BENEFIT/COST ANALYSIS OF GEOTHERMAL TECHNOLOGY R&D

Volume I: Summary of the Analysis

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Benefit/Cost Analysis of Geothermal Technology R&D

Volume I: Summary of the Analysis

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May 1979

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Contract Sponsor: DOE/DGE

Contract No.: EG-77-C-01-4014
Project No.: 1526N
Dept.: W-52

DGE-4014-10
Distribution Category UC-66d

The MITRE Corporation
Metrek Division
1820 Dolley Madison Boulevard
McLean, Virginia 22102

MITRE Technical Report
MTR-7980, Volume I

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ABSTRACT

This is a summary report of the results of benefit/cost analyses of 113 research and development (R&D) projects being funded by the Utilization Technology Branch (UTB) of the Division of Geothermal Energy (DGE), Department of Energy (DOE). The full analyses of each of the three technology programs are presented in separate volumes:

Vol. II: Geothermal Drilling Technology

Vol. III: Energy Extraction and Conversion Technology

Vol. IV: Geochemical and Materials Engineering

The benefits were computed in terms of the savings resulting from the reduction in the cost of electricity projected to be generated at 27 hydrothermal prospects in the U.S. between 1978 and 2000, due to technological improvements brought about by successful R&D. The costs of various projects were estimated by referring to the actual expenditures already incurred and the projected future budgets for these projects. In certain cases, the expected future expenditures had to be estimated on the basis of the work which would need to be done to carry a project to the commercialization stage.

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EXECUTIVE SUMMARY

This report documents a benefit/cost analysis of 113 R&D projects of the Utilization Technology Branch (UTB) of the Division of Geothermal Energy, U.S. Department of Energy. The purpose of the analysis was to compare the relative merits of the R&D projects on a uniform basis, and to estimate the probable economic impacts of the projects upon the cost of geothermal electricity in the United States between the years 1979 and 2000.

The methodology of this analysis was designed to assess projects from a program manager's point of view. The methodology focuses primarily on the relative probable economic impacts of R&D projects, rather than on an overall economic impact of the UTB program considered as a whole.

The R&D projects were grouped into sets of R&D activities that promise to deliver technologically practical products that might improve the economics of geothermal electricity production. The analysis identified 55 such sets of R&D activities, of which 47 were found to offer cost-reducing impacts.

The reported benefits are restricted to economic impacts that these products of R&D are deemed likely to have on the total costs - capital, operation, and maintenance - of producing electricity from U.S. liquid-dominated geothermal prospects. The potential impacts of these projects on other geothermal energy applications - direct heat, geopressured, and hot dry rocks - are large in many instances, but are outside of the scope of this analysis, except for a few special cases.

The reported R&D costs are the Federal outlays estimated by MITRE analysts as necessary to bring the products of the R&D activities into the commercial market place in a timely manner. In some cases these costs go beyond currently planned UTB budgets.

The benefit/cost (B/C) ratios of the UTB activities are generally very high. Of the 48

FIGURE E-1
ESTIMATED BENEFITS AND COSTS OF UTILIZATION TECHNOLOGY
BRANCH R&D ACTIVITIES

activities with positive benefits, 39 have optimistic B/C ratios of greater than 10 to 1, and 33 have pessimistic B/C ratios of greater than 10 to 1.

The total expected benefit for the UTB R&D activities is in the range of \$2.1 - \$4.2 Billion (Present value, 1978 \$, 10% discount rate). This benefit is between 18% and 38% of the \$10.9 Billion electricity total cost estimated for use of current technology at 27 U.S. liquid-dominated geothermal prospects in the years 1979 - 2000. The mid-point of the benefit range indicates that the UTB R&D activities, if continued to completion, would save about one-third of the cost of using current technology at these prospects.

Figure E-1 compares cumulative benefits to cumulative R&D costs, and displays the optimistic benefit/cost ratios for the R&D activities of the three subprograms of the UTB.

The Geothermal Drilling Technology Program promises a benefit of \$1.0 - \$2.0 Billion from an R&D cost of \$12.2 Million. The B/C ratio ranges from 85 to 162. The Geothermal Energy Extraction and Conversion Technology Program promises a benefit of \$0.8 - \$1.7 Billion from an R&D cost of \$23.6 Million. The B/C ratio ranges from 32 to 74. The Geochemical and Materials Engineering Program promises a benefit of \$0.4 - \$0.9 Billion from an R&D cost of \$23.3 Million. The B/C ratio ranges from 18 to 40. Because of small overlaps between certain impacts of the subprograms, the \$2.1 - \$4.2 Billion expected benefit for the UTB is slightly less than the sum of expected benefits of the three subprograms.

The estimated benefits are based on a specific scenario of the rate at which hydrothermal electric plants will be installed at each of the 27 geothermal prospects during 1979 - 2000. The reference scenario was developed by the Division of Geothermal Energy and adopted for use in planning and analysis studies by the Interagency Geothermal Coordinating Council in 1977. If the electricity capacity and generation goals of the scenario are not met, the dollar benefits from

R&D estimated in this analysis will be reduced in proportion to the shortfall in installed capacity. However, the estimates of the percentage reduction in electricity cost at the developed prospects should be fairly accurate, even if many of the power plants postulated in the scenario are not in operation by 2000.

1.0 INTRODUCTION

This report documents a benefit/cost analysis of 113 R&D projects of the Utilization Technology Branch (UTB) of the Division of Geothermal Energy (DGE), U.S. Department of Energy (DOE). The R&D activities of the Branch are conducted through contracts with industrial R&D firms and DOE Laboratories.

During the analysis preparation period (calendar 1978), the technical direction of the UTB R&D activities was managed through the three R&D Programs of the Branch:

- Program I - Geothermal Drilling Technology
- Program II - Geothermal Energy Extraction and Conversion Technology
- Program III - Geochemical and Materials Engineering

The approach and methodology for this analysis were developed by MITRE in late 1977, in conjunction with the Branch Chief and three Program Managers of the UTB (1). The approach defines "benefits" as estimated cost-reducing impacts of specific R&D projects upon electricity-generation costs at 27 U.S. hydrothermal geothermal prospects during 1979 - 2000.

The analysis represents a confluence of two streams of work in the DGE program. First, during the past two years the Chief of the Utilization Technology Branch and the three Program Managers have been encouraging their R&D contractors to formulate at least preliminary estimates of the probable technical impacts and the potential economic value of the improved geothermal

components and processes being developed. Many such analyses have been performed, and have contributed to the technical direction of the UTB program, but there has been no consistent frame-work for analyzing the likely overall economic impact of the R D activities.

Second, MITRE has been supporting DGE with respect to the planning and evaluation of the general DGE program. Important milestones leading up to the present analysis include: a benefit/cost analysis of DGE activities taken as a whole (2), the preparation of the first integrated site-specific data base on U.S. geothermal prospects (3), and a preliminary benefit/cost analysis of some aspects of the Geothermal Drilling Technology R&D Program (4).

The two streams were joined by the preparation of an integrated approach to benefit/cost analysis of UTB R&D activities (1). The approach emphasizes the evaluation of the relative merits of R&D projects from the program manager's point of view.

1.1 Purpose and Scope

The purposes of this analysis are shown in Table 1. The scope of this analysis is described in Table 2.

TABLE 1

PURPOSES OF THE BENEFIT/COST ANALYSIS

- Provide a uniform basis for evaluating the probable impacts of various R&D projects on the cost and/or availability of geothermal electricity at 27 designated geothermal prospects between 1979 and 2000;
- Estimate the likely technical and economic impacts of 113 R&D projects in the three R&D Programs of the Utilization Technology Branch of DGE;
- Evaluate the relative cost effectiveness of the expenditures on these projects;
- Present the results of this analysis in a manner that would make it easier for the responsible DOE officials to monitor the progress and the potentially changing relative importance of the various R&D projects and areas with regard to DGE programmatic goals.

TABLE 2

SCOPE OF BENEFIT/COST ANALYSIS

- The analysis is focused on benefits expected from the likely products of specific R&D projects or groups of projects. The unit of analysis is called an R&D "subelement": a group of R&D contracts and future activities that appear to be sufficient to deliver a useful product to the geothermal industry.
- Benefits are limited to those estimated for U.S. hydrothermal (liquid-dominated) geothermal electric plants in the years 1979-2000. Benefits from geopressured and hot dry rock geothermal sources are estimated in only a few exceptional cases, which are so noted. Benefits from R&D impacts on direct-heat applications are not considered.
- Benefits are calculated against the DGE scenario for the expected development of electric power plants at 27 designated hydrothermal prospects in nine states (5).
- Benefits are calculated using engineering/economic models that are sensitive to the major physical characteristics of the specific prospects. The benefits are reported here only in terms of the estimated cost savings totalled across all the prospects.
- Cost-saving benefits include economic impacts of R&D subelements on capital, operating, and maintenance costs for electricity production.
- The estimated benefits include consideration of the likelihood of technical and commercial success of the R&D projects.
- R&D costs include only past, present, and future Federal R&D outlays by the Division of Geothermal Energy. Collateral contributions from other sources are not included.
- No attempt was made to sum the predicted impacts of R&D on the final cost of electricity at specific geothermal prospects, nor was any attempt made to estimate how the economic benefits might be distributed to various parties.

**FIGURE 1
ORGANIZATION OF THIS REPORT**

1.2 Organization of this Report

The organization of the report is shown in Figure 1.

The three R&D Programs of the UTB are analyzed in separate volumes, II, III, and IV. The technical details of the benefit/cost analyses of the 56 R&D subelements (project groups) are presented in appendices to those volumes.

The results and conclusions from Volumes II-IV are collected in Sections 3.0 and 4.0 of this Volume. Recommendations for updating and refining the benefit/cost analyses are made in Section 4.0.

Appendix A presents the benefit/cost analysis results of the 56 individual R&D Subelement project groupings analyzed here.

Appendix B describes the elements of the general analytical approach and methods that were common to all of the benefit/cost analyses.

(N = Number of Program Elements at each Level.)

FIGURE 2
HIERARCHY OF R&D ACTIVITIES FOR THE BENEFIT/COST ANALYSIS

2.0 GENERAL APPROACH AND DEFINITIONS

Figure 2 shows the logical hierarchy used to analyse R&D activities.

The top and bottom levels of the hierarchy, Programs and Projects, reflect the managerial and contractual structure of the DGE Utilization Technology Branch activities.

The middle two levels, Technical Areas and Subelements, reflect how DGE projects were grouped during the benefit/cost analysis to trace the potential technical and economic impacts of the Projects. The Technical Area level was formulated to allow determinations of how R&D project impacts on components and processes could be translated accurately into effects on hydrothermal electric system performance and costs. The R&D Subelement level was formulated to group projects into sets that promised practical, applied, commercializable R&D products.

FIGURE 3
APPROACH FOR THE BENEFIT/COST ANALYSIS

Figure 3 shows a schematic outline of the general approach. The details of the methods can be found in Appendix B to this volume.

The approach had four major elements:

- (1) Quantitative analysis of the technical and economic impacts of the expected products of groups of R&D projects upon hydrothermal electric plant subsystems, and the year in which those impacts would occur.
- (2) Use of prospect-specific data and two computer-based engineering cost models, GELCOM and WELCST, to estimate how much the R&D impacts would reduce the cost (in 1978 \$) of electricity for one 50 MWe net plant at each of the 27 prospects. GELCOM models the plant and financing (6). WELCST models the capital cost of wells (7).
- (3) Use of the DGE 1979-2000 hydrothermal development scenario (5) and the MITRE-devised "GEOBEN" scheduling, discounting, and summation computer code to estimate the total dollar savings expected from the R&D impacts across the 27 prospects and 22 years. This saving is the "benefit".
- (4) Estimation of past, present, and future DGE R&D costs and calculation of benefit/cost ratios.

The technical terms used to explain the approach and results are defined in Table 3.

TABLE 3

DEFINITIONS FOR THE ANALYSIS

- R&D Subelement - A set of one or more R&D contracts or future activities that are expected to produce a commercialiable practical improvement in a geothermal electrical system component or process.
- Sunk Costs - R&D costs incurred through FY1977, inflated at 10%/year to 1978 dollars.
- Planned Costs - Expected future (including FY1978) R&D costs to the Federal program. These include costs planned by DGE, and in many cases "additional" costs estimated by MITRE to be required to bring the anticipated products of the subelement to commercialization. Expressed in 1978 present value; discount rate = 10%.
- Date of Commercialization - Year in which the product of the subelement is expected to be available for commercial incorporation into geothermal wells or electric plants.
- Estimated Benefit - Savings in the costs of electricity production in the years 1979-2000 at the 27 U.S. liquid-dominated geothermal prospects included in the hydrothermal electricity development scenario. This benefit is based on technical considerations only, and is the modelled consequence of either a pessimistic or optimistic estimate of the degree to which the R&D subelement activities will alter technology performance and/or costs expressed in 1978 dollars; assumed discount rate of 10% per year.
- Degree of Success - A scaling factor between 0.0 and 1.0 that reflects MITRE's estimate of the degree to which the possible (estimated) benefit will be delivered commercially. The estimate of degree of success includes such considerations as probability of technical success in the R&D activities, competition between subelement products for shares of the same market, and sundry factors that could affect commercial use of the R&D product.

(Continued)

TABLE 3 (Continued)

DEFINITIONS FOR THE ANALYSIS

- Expected Benefit - Product of the estimated benefit and degree of success: final estimate of how much savings in the cost of electricity production is most likely to result from the R&D subelement.
- Figure of Merit - Expected benefit divided by planned R&D costs. This is the benefit/cost ratio for the R&D subelement. It disregards sunk costs, to provide a forward look of the relative merit of continued investment in the R&D subelement.
- "From Start" Figure of Merit - Expected benefit divided by sum of sunk plus planned costs. This value provides an estimate of the relative value of each subelement throughout its entire life-span. In some places in this report this is also called the "Historical" Figure of Merit.

TABLE 4

BENEFIT/COST RESULTS FOR THE THREE PROGRAMS OF THE UTILIZATION TECHNOLOGY BRANCH OF DGE

R&D Program	Number of Technical Areas	COST (\$1000, 1978)		EXPECTED BENEFIT ¹ (\$Millions, 1978)		FIGURE OF MERIT ²		FROM START FIGURE OF MERIT ³	
		Sunk + FY77	Planned FY78 +	Pessi- mistic	Opti- mistic	Pessi- mistic	Opti- mistic	Pessi- mistic	Opti- mistic
Geothermal Drilling Technology	6	6,994	12,199	1,037.3	1,969.9	85.0	161.5	54.0	102.6
Geothermal Energy Extraction & Conversion Technology	7	14,849	23,570	771.6	1,739.4	32.7	73.8	20.1	45.3
Geochemical and Materials Engineering	4	6,111	23,328	427.1	927.5	18.3	39.8	14.5	31.5
Utilization Technology Branch Total	17	27,954	59,097	2,236.8	4,636.8	37.8	78.5	25.7	53.3

(1) Product of estimated benefit and degree of success.

(2) Includes planned and additional costs only.

(3) Includes sunk, planned, and additional costs.

3.0 RESULTS

The results of the analysis are presented in top-down fashion.

3.1 Program and Branch Totals

The summed benefits and costs for the Utilization Technology Branch and its three R&D programs are shown in Table 4.

The total expected benefit for the program is in the range of \$2.2 - \$4.6 Billion (Present Value, 1978 \$; 10% discount rate). This benefit is between 20% and 42% of the \$10.9 Billion (Present Value, 1978) electricity total cost estimated for the 27 prospects in the 1979-2000 hydrothermal electric scenario. The mid-point of the benefit range indicates that the Utilization Technology Branch R&D activities, if continued to completion, could cut the composite cost of geothermal electricity by about one third, compared to the cost using current technology.

While not analyzed in detail, the percentage savings will be the greatest at prospects where the wells are relatively deep, the resource temperature falls in the moderate range, and the fluid salinity is high.

With respect to both the total expected benefit, and both current and "from start" benefit/

cost ratios (Figures of Merit in Table 4), the Geothermal Drilling Technology Program provides the greatest leverage, followed by the Geothermal Energy Extraction and Conversion Technology Program, and then the Geochemical and Material Engineering Program. This relative leverage is not surprising because of differences between the programs with respect to both the kinds of technology, and the susceptibility of that technology to being improved by R&D efforts. It is important to note that each of the three programs is estimated to return at least \$13 for every federal dollar spent on it.

3.2 Technical Areas in the Three Programs

Tables 5, 6, and 7 present costs, benefits, and benefit/cost ratios for the technical areas of the Three Programs.

The areas that appear to offer exceptional leverage in terms of both benefits and benefit/cost ratios are: Drill Bits, Downhole Drilling Motors, Extraction and Conversion System Studies, and Fluid Extraction.

The two areas with the lowest figure of merit are: Prime Movers, and Heat Rejection. These studies seek to improve well developed technology, where only marginal improvements might result from R&D.

TABLE 5

BENEFIT/COST RATIOS OF STANDARD TECHNICAL AREAS
IN THE GEOTHERMAL DRILLING TECHNOLOGY R&D PROGRAM

STANDARD TECHNICAL AREA	COST (\$1000, 1978)		EXPECTED BENEFIT ¹ (\$Millions 1978)		FIGURE OF MERIT ²		FROM START FIGURE OF MERIT ³	
	SUNK +FY77	PLANNED FY78+	PESSI- MISTIC	OPTI- MISTIC	PESSI- MISTIC	OPTI- MISTIC	PESSI- MISTIC	OPTI- MISTIC
Drill Bits	3,296	2,607	558.3	836.7	214.2	320.9	94.6	141.7
Downhole Motors	1,304	3,139	204.4	474.0	65.1	151.0	46.0	107.0
Drilling Fluids	494	3,239	121.0	248.2	37.4	76.6	32.4	66.5
Logging Sondes	805	1,490	65.3	192.4	43.8	129.0	28.5	83.8
Measurements for Drilling & Pumps	868	1,624	60.0	160.0	36.9	98.5	24.1	64.2
Descaling	227	100	28.3	58.6	283.0	586.0	86.5	179.0
ENTIRE PROGRAM	6,994	12,199	1,037.3	1,969.9	85.0	161.5	54.0	102.6

¹ Product of calculated benefit and degree of success.

² Includes planned and additional costs only.

³ Includes sunk, planned, and additional costs.

TABLE 6

BENEFIT/COST RATIOS OF THE STANDARD TECHNICAL AREAS IN THE
GEOTHERMAL ENERGY EXTRACTION AND CONVERSION TECHNOLOGY R&D PROGRAM

STANDARD TECHNICAL AREA	COST (\$1000, 1978)		EXPECTED BENEFITS ¹ (\$Millions 1978)		FIGURE OF MERIT		FROM START FIGURE OF MERIT ²	
	SUNK FY77	PLANNED FY78	PESSI- MISTIC	OPTI- MISTIC	PESSI- MISTIC	OPTI- MISTIC	PESSI- MISTIC	OPTI- MISTIC
Reservoir Stimula- tion	685.	9,302.	188.0	530.9	20.2	57.1	18.8	53.2
Fluid Extration	2,048.	3,878.	58.1	192.4	15.0	49.6	9.8	32.5
Binary Technology	4,153.	6,739.	136.4	264.7	20.2	39.3	12.5	24.3
Prime Movers	6,237.	1,899.	89.4	175.8	47.1	92.6	11.0	21.6
System Studies	1,181.	6,602.	301.5	599.9	45.7	90.8	38.7	77.0
Well Head Genera- tor ³	1,218	14,480.	14.1	33.4	1.0	2.3	0.9	2.1
Heat Rejection	908.	1,045	23.3	36.1	22.3	34.5	11.3	16.8
Entire Program	16,430.	43,945.	810.7	1,833.2	18.4	41.7	13.4	30.4
50 MWe Plants ⁴	14,849	23,570	771.6	1,739.4	32.7	73.8	20.1	45.3

¹Product of the estimated benefit and degree of success

²Includes sunk R&D costs

³Includes subelement 2-4-C, Helical Screw Expander

⁴Excludes Well-Head Generators and Hybrid Geothermal-Fossil Plant Subelements

TABLE 7

BENEFIT/COST RATIOS OF STANDARD TECHNICAL AREAS IN
GEOCHEMICAL AND MATERIALS ENGINEERING PROGRAM

STANDARD TECHNICAL AREA	COST (\$1000, 1978)		EXPECTED BENEFIT ² (\$Millions 1978)		FIGURE OF MERIT ¹		FROM START FIGURE OF MERIT ³	
	SUNK ←FY77	PLANNED FY78→	PESSI- MISTIC	OPTI- MISTIC	PESSI- MISTIC	OPTI- MISTIC	PESSI- MISTIC	OPTI- MISTIC
Precipitation and Geochemistry	1314	3305	72.7	141.9	22.0	42.9	15.7	30.7
Materials	3776	10200	227.1	443.00	22.3	43.4	16.3	31.7
Measurement, Testing, & Process Control Techno- logy	1021	3710	27.4	200.9	7.4	54.1	5.8	42.5
Waste Management	0	6113	100.0	141.7	16.4	23.2	16.4	23.2
ENTIRE PROGRAM	6111	23328	427.1	927.5	18.3	39.8	14.5	31.5

¹Excluding costs of projects which have been completed or terminated.²Product of calculated benefit and degree of success.³Includes sunk costs.

3.3 Benefit/Cost Ratios for Individual R&D Subelements

The results for the 55 individual Subelements are too voluminous to present here. They are attached as Appendix A for the interested reader.

Figures 4, 5, and 6 display cumulative benefit/cost curves for the three Programs. These curves result from ranking the R&D Subelements within each program in order of decreasing optimistic Figure of Merit. That is, the Subelement with the highest optimistic estimate of current (w/o sunk costs) benefit/cost ratio is the left-most subelement in each graph.

FIGURE 5
EXPECTED BENEFIT VS. PLANNED PLUS ADDITIONAL R&D COST
FOR THE GEOTHERMAL ENERGY EXTRACTION AND UTILIZATION PROGRAM
(EXCLUDING PROJECTS ON HYBRID CONCEPT AND WELL-HEAD GENERATOR)

FIGURE 6
EXPECTED BENEFIT VS. PLANNED PLUS ADDITIONAL R&D COST
FOR THE GEOCHEMICAL & MATERIALS ENGINEERING PROGRAM

3.4 Factors that Affect the Estimated Benefits

The benefits estimated in this analysis are based on a number of assumptions, as discussed in detail in Appendix B. Since the assumptions have various degrees of uncertainty associated with them, it is important to understand how changes in the assumptions might alter the estimated benefits.

Three major assumptions are considered here: Potential overlaps of technical (engineering and economic) impacts of R&D subelements, level of technical and commercial success postulated for subelements, and using the IGCC Planning scenario as a basis for estimating the number of hydrothermal-electric plants to go into operation by 2000.

Overlaps Between Impacts of R&D Subelements - While much care was taken to eliminate overlapping impacts that could result in a double-counting of economic benefits, we are aware that two types of overlap exist in the results shown in Tables 4,5,6 and 7.

The first type consists of simple overlaps between subelements. For example, certain impacts postulated for components of drill bits and logging sondes are credited both to device development in the Geothermal Drilling Technology Program and to materials development in the Geochemical and Materials Engineering Program. We believe that there are no major overlaps of this type within each program, but that such overlaps between the three programs

will reduce the overall benefit of the total UTB program by about 1 % in the pessimistic totals and 2 % in the optimistic totals.

The second type of overlap occurs because some subelements impact on the cost per geothermal wells, while other subelements impact on the number of wells required per net kilowatt capacity. In the method and computer models used here, the economic benefits from well cost reduction were calculated against the nominal baseline for well numbers requirement, and the economic benefits from well number requirement reduction were calculated against the nominal baseline for well costs. However, each of these baselines is of course reduced in magnitude by the impacts of R&D, which leads to an economic benefit slightly less than that calculated assuming the nominal baselines.

For example, if well costs were to be reduced 30 percent, and the number of wells reduced by 20 %, the final cost of all wells would be $(1.0 - 0.3) \times (1.0 - 0.2) = 0.56$ times the original nominal cost. Simple addition of the calculated impacts, as was done in Table 4, would suggest that the final cost of all wells would be $(1.0 - (0.3 + 0.2)) = 0.50$ times the original nominal cost. Consequently the calculated total benefit would have been overestimated by $100 \times (0.56 - 0.50)/0.50 = 12\%$.

Close examination of the benefit estimates indicates that this second type of overlap

induced a double count of about 6 % in the pessimistic totals, and a double count of about 8 % in the optimistic totals. Thus the two types of overlap combined result in a double count of about 7 % in the pessimistic totals and about 10% in the optimistic totals.

Degree of Success of Subelements - Among the important considerations in this analysis are the estimates of the Degree of Success of each R&D subelement. The "Degree of Success" is a numerical factor, ranging between 0.0 and 1.0, that is the analysts' prediction of what fraction of the ideal technical impacts from each subelement will be achieved technically, and reach commercial use. These estimates are a necessary link between the technical performance goals and the final economic impact of an R&D effort. However, such estimates can not be other than subjective, no matter how informed their basis. Therefore it is important to estimate how large an effect they might have on the overall estimate of benefits.

The average value of the estimated Degree of Success, across all the subelements, is about 0.6, suggesting that about 60% of the potential economic impacts of the ideal technical goals will reach commercial use. If the actual achievement, over the coming years, slips to 50% instead of 60%, about 17% of the expected benefits would not be realized. It is important to note that the real outcome could be higher than that estimated, but this result

is probably less likely than a shortfall.

The IGCC Planning Scenarios - The size of the total benefit from this R&D program depends on the number of geothermal electric plants that will come into operation between 1979 and 2000, and the dates at which they come into operation. As discussed in detail in Appendix B, Approach and Methods, the Interagency Geothermal Coordinating Council (IGCC) 1977 hydrothermal-electric planning scenario was used as the reference set of plant sites and installation schedules. As shown in Table B-1 in Appendix B, that scenario postulates 18,600 MWe capacity being installed at 372 plants at 27 prospects in the years 1983-2000.

The IGCC scenario is considered by some to be an ambitious one. If these installation goals are not met, the dollar amount of the benefits estimated in this analysis will be reduced proportionately. Very recent analyses suggest that the installed capacity for hydrothermal electric plants will be on the order of 7,000 to 8,000 MWe by 2000.

Fassbender and Bloomster have derived supply curves for the U.S. hydrothermal electric resource (8). Using the supply curve based on their "1990 R&D Results Scenario", which is in general similar to the R&D outcomes derived here, at a busbar cost of 30 mills/kWh, about 2,500 MWe-centuries of net output are available. This is equivalent to about 8,300 MW installed capacity of plants with a 30 year lifetime. Kruger and Roberts, in a recent assessment of

estimates by electric utilities of near and mid-term geothermal electric development, indicate that about 7,000 MWe installed capacity of hydrothermal electric is "probable" by 2000 (9). Both of these estimates are markedly lower than the 18,600 MWe postulated in the IGCC scenario.

If the Kruger and Roberts estimate of 7,000 MWe is taken as the probable year 2000 installed capacity, then the benefits will be on the order of $100 \times 7/18.6 = 38\%$ of those estimated in the present analysis.

Table 8 shows the effects of altering these three major assumptions. By far the largest effect comes from changing the estimate of the year 2000 installed hydrothermal electric capacity (Assumption 4 in Table 8). If all three factors are altered to the down side, the expected benefit of the UTB program becomes \$650 Million (pessimistic) to \$1,310 Million (optimistic). The benefit/cost ratio for the program then falls into the range of 11:1 to 22:1.

It should be noted that the various estimates of the percentage cost reduction per plant are certainly affected by Assumption 2 (Overlaps), possibly affected by Assumption 3 (Degree of Success), and not affected by Assumption 4 (Planning Scenario). Therefore, MITRE's best estimate of the busbar cost reduction due to the combined effects of this R&D program falls in the range of 18% to 38%, depending on resource characteristics.

TABLE 8

EFFECTS OF ALTERED ASSUMPTIONS ON EXPECTED BENEFITS
AND BENEFIT/COST RATIOS FOR TOTAL UTB PROGRAM

ASSUMPTIONS	EXPECTED BENEFIT \$10 ⁶		FORWARD LOOKING BENEFIT/COST RATIO	
	PESSIMISTIC	OPTIMISTIC	PESSIMISTIC	OPTIMISTIC
1. Baseline, as Estimated from Sums of Subelements Benefits	2,240.	4,640.	38	78
2. Benefits Reduced 7% to 10% due to Overlaps Between Subelements	2,080.	4,180.	35	71
3. Typical Degree of Success Lowered from 0.6 to 0.5	1,870.	3,870.	32	59
4. Reduction of Year-2000 Installed Capacity from 18,600 to 7,000 MWe	840.	1,740.	14	30
5. Assumptions 2 and 4 Combined	780.	1,570.	13	27
6. Assumptions 2, 3, and 4 Combined	650.	1,310.	11	22

4.0 CONCLUSIONS

This analysis is focussed on projects, rather than the UTB program as a whole. Nonetheless, relationships between projects are clear only when they are discussed in the context of the entire program.

The range of benefit/cost ratios across individual projects (subelements) is quite large. This reflects the broad range of the technical problems being dealt with, the relative susceptibility of the problems to R&D, the differing economic impacts that technical solutions could have, and the relative magnitudes of sunk and planned costs. It is emphasized that this benefit/cost analysis is forward-looking, over a twenty-two year time span, and over R&D activities in a five to ten year time span. Many of the expected benefits will not be realized if the R&D activities that support them were to be terminated prematurely.

The largest benefits come from projects that promise either to reduce the cost per unit flow of geothermal fluid, or to reduce the amount of flow required per kilowatt-hour of output. This shows up in the relatively large benefits associated with: faster drilling, well-stimulation methods, downhole pumps, heat exchangers, rotary separator, and the plant efficiency improvements due to the systems studies in the energy conversion area.

There appear to be essentially no technical go/no-go problems in the geothermal utilization technology area. In only one area, waste management, does it appear that potential technical problems could preclude development at certain prospects. In the long run, any severe problems of this type will probably have to be dealt with on a site-specific basis. Thus, most of the predictable impacts of this R&D program will result in cost reductions, which impact energy output by allowing geothermal hydrothermal-electric plants to be increasingly competitive with other sources of energy.

It is known from previous MITRE analyses for DOE that the projected impacts of this R&D program are not, by themselves, sufficient to bring most of the 27 discussed geothermal prospects into competitiveness. However, when the R&D impacts are linked with the financial incentives for geothermal energy provided by the 1978 National Energy Act, the combined impacts make many of these prospects cost-competitive, or nearly so (5).

Federal funds are not the only monies being invested in these R&D efforts. Many of the projects assessed in this analysis have received substantial cost and effort-sharing inputs from R&D contractors. In many instances industrially funded development of devices initiated by these projects will continue after federal funding is completed. The magnitudes of industrial contributions to these R&D efforts is almost impossible to measure, and for that reason

they have not been treated in this analysis.

It appears, however, that the UTB programs have been very successful in obtaining continuing financial contributions from the growing geothermal equipment and development industry. The UTB program thus shows many signs of meeting the needs of geothermal energy development by focussing federal support on the high risk front-end portion of R&D efforts, and by targetting that support toward achievable technical improvements that could have major economic impacts.

The general conclusions of the analysis with respect to each of the three UTB sub-programs are presented in Tables 9, 10, and 11.

TABLE 9

CONCLUSIONS: DRILLING TECHNOLOGY PROGRAM

- The estimated as-planned benefit/cost ratio for the Geothermal Drilling Technology Program falls somewhere between 85 and 162. This program should yield a very good return on the Federal R&D investment.
- There are a few instances of overlap of technical and economic impacts between this program and the other two UTB programs. Elimination of these overlaps would reduce the benefit cost ratios by a small but as yet undetermined amount.
- As an average across the U.S. scenario for geothermal electricity development, the drilling program activities could reduce electricity costs by 10% to 18%. The cost of geothermal wells at these sites could be reduced by 20% to 39% by 1985.
- Most of the expected technology improvements will be ready for commercial application by 1985.
- The largest share of the expected benefits come from R&D activities in the Drilling Bits area.
- Continued R&D activity is needed to realize potentially large cost savings in the areas of Downhole Motors and Geothermal Drilling Fluids.
- An additional benefit of between \$150. million and \$330. million might be obtained at geopressured and hot dry rock sites if the SUBTERRENE project is reinitiated.

TABLE 10

CONCLUSIONS: ENERGY EXTRACTION AND CONVERSION TECHNOLOGY PROGRAM

- The estimated as-planned benefit/cost ratio for the Geothermal Drilling Technology Program falls somewhere between 31 and 62. This program should yield a good return on the Federal R&D investment.
- There are a few instances of overlap of technical and economic impacts between sub-elements both within this program, and between this program and the other two UTB programs. Elimination of these overlaps would reduce the benefit/cost ratios by a small amount.
- As an average across the U.S. for geothermal electricity development, the energy extraction and conversion program activities could reduce electricity costs by 7% to 16%.
- The Prime Movers standard technical area has the highest estimated pessimistic and optimistic benefit/cost ratios. These values are 47 to 93, respectively.
- Although significant improvements in the energy conversion efficiency appear to be unlikely (due to the relatively advanced current state of the art in this area), the System Studies standard technical area (theoretical analyses of advanced power cycles and conversion schemes) has a relatively high benefit/cost ratio. This occurs because the utilization of the output of this technical area does not require any significant capital expenditure.
- The Heat Rejection standard technical area has relatively low values of benefit/cost ratios due to the advanced state of the art in this area.
- The inclusion of hot dry rock and geopressured systems among the potential recipients of benefits of R&D in certain technical areas (mainly Fluid Extraction, Binary Technology and System Studies) would increase the benefit/cost ratios for these technical areas significantly.

TABLE 11

CONCLUSIONS: GEOCHEMICAL & MATERIALS ENGINEERING PROGRAM

- The estimated as-planned benefit/cost ratio for the Geochemical and Materials Engineering Program falls somewhere between 18 and 40. This program should yield a moderate to good return on the Federal R&D investment.
- There are a few instances of overlap between expected products of this program and of the other two programs. Elimination of these overlap would reduce the benefit/cost ratios by a small amount.
- As an average across the U.S. scenario for geothermal electricity development, the activities of the geochemical & materials engineering program could reduce electricity costs by 4% to 8%.
- R&D in the Materials Development area yields the highest impacts even when direct heat and geopressured applications are excluded.
- R&D activities in the area of Precipitation and Geochemistry show evidence of becoming more goal-orientated.
- Although there are high benefit projects, more goal-orientated definitions are needed in the Measurement, Testing and Process Control technology area.
- Large additional benefits can be expected if the products of this program were to be applied to hot dry rock and geopressured geothermal energy systems.

5.0 RECOMMENDATIONS

The recommendations made here apply to use and update of the results and conclusions of this benefit/cost analysis.

(I) The following estimates should be updated at regular intervals:

- Impacts of R&D Subelements on system parameters,
- Estimated degree of success of each Subelement, and
- The "power-on-line" projections of the 1979-2000 Hydrothermal Development Scenario.

The results of this analysis should be recomputed after these updates.

(II) The expected benefits of individual R&D Subelements should be tabulated to show their probable impacts on specific sites.

(III) All new projects/Subelements should be analyzed for estimating their expected benefit/cost ratios prior to their initial funding.

(IV) A periodic review of various program areas should be conducted to deal with situations involving overlapping objectives of different projects/subelements.

(V) A dynamic simulation model should be developed to handle the uncertainties associated with costs, degree of success, schedule and impacts of various subelements.

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APPENDIX A

BENEFIT/COST RESULTS FOR
INDIVIDUAL R&D SUBELEMENTS

APPENDIX A - EXPLANATION

The three tables in this appendix present the results of the benefit/cost analyses of the 56 Subelements of the R&D Programs of the Utilization Technology Branch (UTB) of the Division of Geothermal Energy.

In the process of analyzing the projects, a coding system was developed and used throughout the four volumes of this report. The three Programs of the UTB are coded with numbers, with Program 1 being the Geothermal Drilling Technology Program, 2 the Geothermal Energy Extraction and Conversion Technology Program, and 3 the Geochemical and Materials Engineering Program. The Standard Technical Area number is next, separated by a hyphen from the program number. The project number is last. For example project 3-2-09 is the ninth project in area 2 of the geochemical and materials engineering program. A subelement is designated with a letter in place of the project number, (e.g., subelement 3-2-C)

TABLE A-1
BENEFITS AND PLANNED COSTS OF THE GEOTHERMAL DRILLING TECHNOLOGY R&D PROGRAM SUBELEMENTS

SUBEL- EMENT CODE	SUBELEMENT TITLE	EXPECTED BENEFIT ¹ (\$10 ⁶ , 1978)				PLANNED COST ² (\$10 ⁶ , 1978)		FIGURE OF MERIT			
		BY SUBELEMENT		CUMMULATIVE				PLANNED COSTS		PLANNED & SUNK COSTS	
		PESSI- MISTIC	OPTI- MISTIC	PESSI- MISTIC	OPTI- MISTIC	BY SUB- ELEMENT	CUMM- LATIVE	PESSI- MISTIC	OPTI- MISTIC	PESSI- MISTIC	OPTI- MISTIC
A. SUBELEMENTS WITH IMPACTS ON DRILLING COSTS AT HYDROTHERMAL ELECTRIC PLAN SITES:											
1-1-B	COMPAX Drill Bit	357.8	514.2	357.8	514.2	0.727	0.727	492	707	359	516
1-1-C	Terra Tek Bits	132.3	208.4	490.1	722.6	0.470	1.197	282	443	102	160
1-2-A	Downhole Motors	204.4	474.0	694.5	1196.6	3.139	4.336	65	151	46	107
1-4-A	Logging Sonde Components	65.3	192.4	759.8	1389.0	1.490	5.826	44	129	28	84
1-1-A	Continuous Chain Bit	61.1	89.8	820.9	1478.8	0.755	6.581	81	119	30	44
1-3-A	High-Temperature Drill Fluids	121.0	248.2	941.9	1727.0	3.239	9.820	37	77	32	66
1-5-A	D.H. Instruments for Drilling	16.0	72.0	957.9	1799.0	1.459	11.279	11	49	8	38
1-1-E	Erosion Drilling	7.1	24.3	965.0	1823.3	0.655	11.934	11	37	5	16
1-1-D	ERODRILL Concept	0.0	0.0	965.0	1823.3	0.000	11.934	0	0	0	0
	SUBTOTAL	965.0	1823.3	965.0	1823.3	11.934	11.934	81	153	53	100

TABLE A-1, (Concluded)

SUBELEMENT CODE	SUBELEMENT TITLE	EXPECTED BENEFIT ¹ (\$10 ⁶ , 1978)				PLANNED COST ² (\$10 ⁶ , 1978)		FIGURE OF MERIT			
		BY SUBELEMENT		CUMMULATIVE				PLANNED COSTS		PLANNED & SUNK COSTS	
		PESSI-MISTIC	OPTI-MISTIC	PESSI-MISTIC	OPTI-MISTIC	BY SUB-ELEMENT	CUMMU-LATIVE	PESSI-MISTIC	OPTI-MISTIC	PESSI-MISTIC	OPTI-MISTIC
B. SUBELEMENTS WITH IMPACTS ON OTHER COMPONENTS OF HYDROTHERMAL ELECTRIC PLANT SITES:											
1-5-B	D.H. Instru. for Pumps	42.5	85.0	1007.5	1908.3	0.000	11.934	---	---	100	199
1-6-A	Cavitation Descaling	28.3	58.6	1035.8	1966.9	0.100	12.034	283	586	87	179
1-5-C	Pump Test Rig	1.5	3.0	1037.3	1969.9	0.165	12.199	9	18	8	16
	SUBTOTAL	72.3	146.6	1037.3	1969.9	0.265	12.199	273	553	77	155
C. SUBELEMENT WITH BENEFIT AT GEOPRESSURED AND HOT DRY ROCK SITES, BUT NOT HYDROTHERMAL SITES:											
1-1-F	SUBTERRENE System	150.0	330.0	1187.3	2299.9	6.035	18.234	25	55	18	40
1-X-X	ENTIRE PROGRAM	----	----	1187.3	2299.9	-----	18.234	65	126	43	84

(1) Product of estimated benefit and degree of success.

(2) Includes MITRE estimates of costs required beyond current DGE plans.

TABLE A-2

BENEFITS AND PLANNED COSTS OF THE GEOTHERMAL ENERGY EXTRACTION AND CONVERSION TECHNOLOGY R&D PROGRAM SUBELEMENTS

SUB-ELEMENT CODE	SUBELEMENT TITLE	EXPECTED BENEFIT ¹ (\$10 ⁶ , 1978)				PLANNED COST ² (\$10 ⁶ , 1978)		FIGURE OF MERIT			
		BY SUBELEMENT		CUMMULATIVE		BY SUB-ELEMENT	CUMMU-LATIVE	(PLANNED COSTS)		PLANNED & SUNK COSTS	
		PESSI-MISTIC	OPTI-MISTIC	PESSI-MISTIC	OPTI-MISTIC			PESSI-MISTIC	OPTI-MISTIC	PESSI-MISTIC	OPTI-MISTIC
A. SUBELEMENTS WITH IMPACTS AT 50 MWe HYDROTHERMAL ELECTRIC PLANT SITES:											
2-5-A	Optimization Studies	240.0	450.0	240.0	450.0	0.250	0.250	960.	1800.	960.	1800.
2-4-B	Rotary Separator	89.3	169.6	329.3	619.6	0.379	0.629	236.	447.	137.	260.
2-1-A	Well Stimulation Analysis	23.5	96.9	352.8	716.5	0.150	0.779	157.	413.	113.	298.
2-7-B	Direct Contact Condenser Research	14.8	22.2	367.6	738.7	0.100	0.879	148.	222.	148.	222.
2-5-B	Geothermal Power Handbook	36.5	89.5	404.1	828.2	0.457	1.336	80.	196.	29.	70.
2-3-C	Binary Direct Contact Heat Exchange	130.3	242.9	534.4	1071.1	2.736	4.072	48.	89.	33.	61.
2-2-C	Downhole Pumps	56.4	138.4	590.7	1209.5	2.532	6.604	22.	55.	13.7	34.
2-1-B	Development of Stimulation Methods	141.1	372.0	731.7	1581.5	7.261	13.865	19.4	51.	18.4	48.
2-2-A	Two-Phase Flow	1.7	38.2	733.4	1619.7	0.828	14.693	2.0	46.	1.3	30.
2-1-C	Rock Mechanics	23.5	62.0	756.9	1681.7	1.891	16.584	12.4	33.	11.2	29.
2-2-B	Gas Lift Technology	0.0	15.8	756.9	1697.5	0.518	17.102	0.0	30.	0.0	30.
2-7-A	Transport and Conversion of Heat	8.5	13.9	765.4	1711.4	0.945	18.047	9.0	14.7	4.6	7.5
2-3-B	Heat Exchange and Binary Fluid	4.3	11.6	769.7	1723.0	0.939	18.986	4.6	12.4	5.2	1.9
2-4-A	Total Flow	0.1	6.2	769.8	1729.2	1.520	20.506	0.0	4.1	0.0	0.8
2-3-D	Binary Shell and Tube Heat Exchange	0.0	6.7	769.8	1735.9	1.912	22.418	0.0	3.5	0.0	3.0
2-3-A	Working Fluid Properties	0.0	1.3	769.8	1737.2	0.407	22.825	0.0	3.2	0.0	2.0
2-3-E	Basic Heat Exchange	1.8	2.2	771.6	1739.4	0.745	23.570	2.4	3.0	2.4	3.0
	SUBTOTAL	771.6	1739.4	771.6	1739.4	23.570	23.570	32.7	73.8	20.1	45.3

TABLE A-2 (Concluded)

BENEFITS AND PLANNED COSTS OF THE GEOTHERMAL ENERGY EXTRACTION AND CONVERSION TECHNOLOGY R&D PROGRAM SUBELEMENTS

SUB-ELEMENT CODE	SUBELEMENT TITLE	EXPECTED BENEFIT ¹ (\$10 ⁶ , 1978)				PLANNED COST ² (\$10 ⁶ , 1978)		FIGURE OF MERIT			
		BY SUBELEMENT		CUMMULATIVE		BY SUB-ELEMENT	CUMMU-LATIVE	(PLANNED COSTS)		PLANNED & SUNK COSTS	
		PESSI-MISTIC	OPTI-MISTIC	PESSI-MISTIC	OPTI-MISTIC			PESSI-MISTIC	OPTI-MISTIC	PESSI-MISTIC	OPTI-MISTIC
B. SUBELEMENTS WITH IMPACTS OF OTHER TYPES OF GEOTHERMAL ELECTRIC PLANT SITES:											
2-4-C	Helical Screw Expander	2.1	5.0	773.7	1744.4	0.430	24.000	4.8	11.5	1.5	3.7
2-5-C	Hybrid Geothermal-Fossil Plants	25.0	60.4	798.7	1804.8	5.895	29.895	4.2	10.2	4.0	9.6
2-6-A	Well Head Generator	7.4	17.5	806.1	1822.3	5.380	35.275	1.4	3.3	1.3	3.1
2-6-B	Gravity Head Binary Plant	4.6	10.9	810.7	1833.2	8.670	43.945	0.5	1.0	0.5	1.0
	SUBTOTAL	39.1	93.8	810.7	1833.2	20.375	43.945	1.9	4.6	1.8	4.3
2-X-X	ENTIRE PROGRAM	810.7	1833.2	810.7	1833.2	43.945	43.945	18.4	41.7	13.4	30.4

¹Product of estimated benefit and degree of success²Includes MITRE estimates of costs required beyond current DGE plans

TABLE A-3

BENEFIT AND PLANNED COST OF THE GEOCHEMICAL AND MATERIALS ENGINEERING PROGRAM SUBELEMENTS *

SUBELEMENT CODE	SUBELEMENT TITLE	EXPECTED BENEFIT ¹ (\$10 ⁶ , 1978)				PLANNED COST ² (\$10 ⁶ , 1978)		FIGURE OF MERIT			
		BY SUBELEMENT		CUMMULATIVE		BY SUBELEMENT	CUMMULATIVE	PLANNED COSTS		PLANNED & SUNK COSTS	
		PESSI-MISTIC	OPTI-MISTIC	PESSI-MISTIC	OPTI-MISTIC			PESSI-MISTIC	OPTI-MISTIC	PESSI-MISTIC	OPTI-MISTIC
3-3-C	NDE Technique	11.2	124.1	11.2	124.1	0.224	0.224	50	554	42	470
3-2-D	Seal Materials	13.4	97.4	24.6	221.5	1.260	1.484	11	77	8	58
3-2-B	Well Cement	85.5	156.7	110.1	378.2	2.350	3.834	36	67	30	54
3-4-B	Waste Utilization	78.4	97.3	188.5	475.5	1.556	5.390	50	62	50	62
3-2-F	Casing and Drill Pipe Mats.	21.2	30.1	209.7	505.6	0.547	5.937	39	55	21	30
3-1-A	Scaling Prediction	72.7	132.3	282.4	637.9	2.956	8.893	25	45	20	37
3-2-H	Dynamic Comp. Materials	11.9	31.1	294.3	669.0	0.783	9.676	15	40	15	40
3-1-E	Scaling Control	0.0	8.5	294.3	677.5	0.249	9.925	0	34	0	18
3-3-A	Sampling and Analysis HB	13.7	20.9	308.0	698.4	0.670	10.595	20	31	12	18
3-2-E	Corrosion of Metals	5.3	8.0	313.3	706.4	0.275	10.870	19	29	3	4
3-2-C	Non-Metallic Const. Mats.	68.9	89.2	382.2	795.6	3.285	14.155	21	27	18	23
3-2-G	Pit.&Loc.Cor.Resist. Mats.	8.6	11.9	390.8	807.5	0.451	14.606	19	26	19	26
3-3-B	Process Instrumentation	2.5	55.9	393.3	863.4	2.816	17.422	1	20	1	17
3-4-A	Spent Fluid Disposal	21.6	39.8	414.9	903.2	2.584	20.006	8	16	8	16
3-2-A	Materials Design HB	12.3	18.6	427.2	921.8	1.249	21.255	10	15	9	14
3-1-C	Silica Scaling	0.0	1.1	427.2	922.9	0.100	21.355	0	12	0	2
3-4-C	Mobile Test Unit	0.0	4.6	427.2	927.5	1.973	23.328	0	2	0	2
3-X-X	ENTIRE PROGRAM	---	----	427.2	927.5	-----	23.328	18	40	14	32

* Excluding 3 non-estimated projects, 1 duplicating effort (subelement 3-1-B), 1 on geopressured well.

(1) Product of estimated benefit and degree of success.

(2) Includes MITRE estimates of costs required beyond current DGE plans.

APPENDIX B

APPROACH AND METHODS OF ANALYSIS

1.0 THE APPROACH

The approach for the benefit/cost analysis was devised by MITRE in conjunction with the UTB Branch Chief and Program Managers (1).

Estimation of R&D costs is a fairly simple process. Estimation of the economic benefits from R&D is both technically difficult and complex. Therefore most of this appendix is devoted to describing how benefits from the R&D projects of the Utilization Technology Branch of DGE were estimated.

FIGURE B-1
MAIN INPUTS AND GLOBAL APPROACH FOR ANALYZING BENEFITS

Figure B-1 shows the two central concepts of the approach in schematic form. Inputs to the analysis are shown on the left, and analysis activities are shown on the right.

The first central concept is that benefits accrue only to practical physical products of R&D activities. That is, to estimate benefits from these applied R&D projects, the projects have to be grouped into small sets (here called "Subelements" of the Program) that promise to deliver a device or process that will reduce the cost of producing electricity from liquid-dominated geothermal reservoirs.

The second central concept is that the magnitude of the benefit should reflect the probable economic impact of these products of R&D upon geothermal power plants deemed most likely to be developed at specific geothermal sites ("prospects") in the U.S. between now and 2000.

The DGE hydrothermal development scenario for the 27 U.S. liquid-dominated geothermal prospects was used here as the basis for how many electric plants are likely to come on line at sites with particular physical characteristics. (2) This reference set of prospects and development schedules was proposed by DGE and adopted by the Interagency Geothermal Coordinating Council in 1977, and has been used for planning and analysis purposes in previous MITRE studies (2,5).

TABLE B-1

ELECTRIC SYSTEMS POWER-ON-LINE SCENARIO;
NUMBER OF 50 MW PLANTS COMING ON LINE IN PERIOD

PROSPECT	TIME PERIODS											TOTAL
	I 1979 -80	II 1981 -82	III 1983 -84	IV 1985 -86	V 1987 -88	VI 1989 -90	VII 1991 -92	VIII 1993 -94	IX 1995 -96	X 1997 -98	XI 1999 -2000	
Salton Sea, CA	--	--	1	3.5	3.5	4	4	4	4	4	4	32
Valles Caldera, NM	--	--	1	2	2	2	4	4	4	4	4	27
Brady Hot Springs, NV	--	--	1	1	2	2	4	4	4	2	--	20
Brawley, CA	--	--	1	1	4	4	4	4	2	--	--	20
Roosevelt Hot Springs, UT	--	--	1	1	1	2	4	4	4	3	--	20
Beowawe, NV	--	--	1	1	1	2	4	4	4	3	--	20
Coso Hot Springs, CA	--	--	--	2	4	6	--	--	--	--	--	12
Mono-Long Valley, CA	--	--	--	1	2	2	--	--	--	--	--	5
Cove Fort-Sulfurdale, UT	--	--	--	1	1	2	4	4	4	4	4	24
Heber, CA	--	--	--	1	1	4	4	4	--	--	--	14
Geysers, CA (Hydrothermal)	--	--	--	4	4	4	4	4	--	--	--	20
East Mesa, CA	--	--	--	1	1	--	--	--	--	--	--	2
Steamboat Springs, NV	--	--	--	1	1	2	--	--	--	--	--	4
Surprise Valley, CA	--	--	--	1	1	4	4	4	4	4	4	26
Chandler, AZ	--	--	--	1	--	2	1	--	--	--	--	4
Leach, NV	--	--	--	--	1	1	4	4	4	4	4	22
Bruneau-Grandview, ID	--	--	--	--	1	2	4	4	4	4	4	23
Lassen, CA	--	--	--	--	1	1	--	--	--	--	--	2
Alvord, OR	--	--	--	--	1	1	2	2	--	--	--	6
Safford, AZ	--	--	--	--	1	--	--	--	1	--	--	2
Weiser-Crane Creek, ID	--	--	--	--	1	2	4	4	4	4	2	21
Vale Hot Springs, OR	--	--	--	--	1	1	2	2	2	2	2	12
Thermo, UT	--	--	--	--	1	--	2	4	3	--	--	10
Raft River, ID	--	--	--	--	1	1	--	--	--	--	--	2
Glass Mountain, CA	--	--	--	--	--	1	--	--	--	--	--	1
Puna, HI	--	--	--	--	--	2	8	8	2	--	--	20
Baker Hot Springs, WA	--	--	--	--	--	1	--	--	--	--	--	1
TOTAL	0	0	6	22.5	37.5	55	67	68	50	38	28	372

The DGE Hydrothermal Electric Development Scenario is shown in Table B-1. Each entry represents one 50 MWe electric power plant. Whereas the table shows the plants grouped in two-year intervals for presentation convenience, the computer data base is segregated into single year intervals.

The importance of using this scenario for this benefit/cost analysis is two-fold. First, because the scenario postulates a certain number of plants entering service in specific years, it fixes the magnitude of the cost of electricity production as the baseline against which savings due to R&D successes can be estimated. Second, because the scenario contains 27 specific sites with different physical characteristics (reservoir temperature, reservoir depth, rock hardness, and fluid salinity), it presents a complex mix of technical problems that R&D activities might solve. Projects that have large impacts at some prospects might have no impacts on others.

Since the postulation of this scenario (ca. 1976) it has become evident that some of the prospects (e.g., Brady Hot Springs) probably will not be used for electricity generation, while other new promising prospects (e.g., Dixie Valley) have surfaced. The scenarios doubtless should be updated. Nevertheless, the original scenarios constitute the best available reference base for estimating relative figures of merit for the R&D subelements, and for estimating impacts of R&D on the total cost of electricity from U.S. liquid-dominated prospects.

FIGURE B-2
PROCEDURES AND MODELS FOR ANALYZING R&D BENEFITS

The procedures and models used to analyze project benefits are displayed in Figure B-2. The named computer-coded models are described in Section 2.0. The important thing to note from Figure B-2 is the sequence in which benefits were evaluated. First, projects were grouped into Subelements. Second, the engineering/economic impacts of each Subelement on geothermal well and plant designs and costs were estimated. Third, an "old" (w/o R&D impacts) cost and a "new" (w/R&D impacts) cost for geothermal electric power production were calculated for each of the 27 prospects. Fourth, these costs are combined with data from the hydrothermal development scenario (number of 50 MWE plants per year per prospect) to estimate total savings per year across all prospects. Fifth, the savings are discounted to present value in 1978 \$.

This final total is called the "estimated benefit". Its magnitude is based, through the above estimation procedure, on an analysts' estimate of the magnitude of a technical and/or cost change that is likely to result from the R&D subelement. These estimates of impacts are made within a range, with the lower value called the "pessimistic" estimate, and the upper value called the "optimistic" estimate. The benefits calculated from these two values are correspondingly called the pessimistic and optimistic benefit.

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An "impact year" or "commercialization year" is also estimated for each subelement. This is the year in which the product of the subelement is estimated to be available on a wide-scale commercial basis for incorporation into geothermal wells or power plants. This date is critical for estimating benefits, because it determines which electric plants in the scenario could have their costs reduced by the R&D product. The dates in the scenario are "power-on-line" dates; they postulate one or more 50 MWe plants entering service by the end of the particular year. The "impact year" assumes commercial availability at the beginning of the stated year. R&D results with an impact year of 1982 could be incorporated into power plants with on-line year of 1983 and later, etc.

One further estimate is made for each subelement: "Degree of Success". This is a scaling factor between 0.0 and 1.0 that reflects MITRE's estimate of the degree to which the possible (estimated) benefit will be delivered commercially. The estimate of degree of success includes such considerations as probability of technical success in the R&D activities, competition between subelement products for shares of the same market, and sundry factors that could affect commercial use of the R&D product.

FIGURE B-3
ESTIMATES FROM R&D SUBELEMENTS USED TO CALCULATE
BENEFIT/COST RATIOS

As shown in Figure B-3, the estimated benefit is multiplied by the Degree of Success to arrive at the expected benefit for the R&D subelement. The expected benefit is the final estimate of how much savings in the cost of electricity production is most likely to result from a given R&D subelement.

The final step in the analysis is the estimation of R&D costs, and the calculation of benefit/cost ratios.

Figure B-3 summarizes the overall process of benefit estimation by focussing on the four types of estimates made for each R&D subelement.

The R&D cost estimate for each subelement includes (a) sunk costs - through F.Y. 1977, (b) current costs - F.Y. 1978, (c) DGE Planned Costs for F.Y. 1979 and later, and (d) Additional costs. "Additional costs" are costs estimated, by MITRE, to be needed to bring the R&D activities of the subelement to the commercially available stage of development. For some subelements, the additional cost represents a substantial part of all anticipated costs.

FIGURE B-4
CURRENT AND HISTORICAL BENEFIT/COST RATIOS

Two types of benefit/cost ratios were calculated, as shown in Figure B-4.

The first, "Figure of Merit", is the expected benefit divided by the sum of current (F.Y. 1978) and future costs. This is the forward-looking benefit/cost ratio for the R&D Subelement. It is viewed as an estimate of the R&D Subelement's suitability for continued or future funding.

The second, "Historical Figure of Merit", is the expected benefit divided by the sum of sunk plus current and future costs. This value provides an estimate of the value or leverage of each subelement throughout its entire life-span.

FIGURE B-5
INPUTS, COMPONENTS, AND DATA BASES FOR GEOBEN CODE

2.0 COMPUTER MODELS FOR ESTIMATING BENEFITS

To calculate the economic impacts of R&D results across the 27 prospects in the hydrothermal development scenario, MITRE prepared a computer-based R&D projects benefits model, "GEOBEN".

Figure B-5 displays the main components of GEOBEN, the data bases that GEOBEN accesses to calculate benefits, and the inputs to the calculation.

WELCST is an engineering cost model of geothermal wells, prepared by MITRE for this benefit/cost analysis (3). WELCST accepts impacts of R&D on any one or more of 80-odd well drilling and completion technological and cost parameters for geothermal wells. The results from WELCST - well costs at the 27 prospects, with R&D impacts and without R&D impacts - are passed on to the GELCOM code through a disk file.

GELCOM is MITRE's Geothermal Levelized Busbar Cost of Electricity Model (4). It includes a geothermal electric plant cost model and a levelized busbar cost model. GELCOM accepts impacts of R&D on any one or more of 49 well and plant life, capital cost, and operating cost factors, as well as specific assumptions about financial requirements. The results from GELCOM - busbar cost of electricity from one 50 MWe electric plant at each of the 27 prospects, with R&D impacts and without R&D impacts - are passed on to the SUMDIP code through a disk file. GELCOM results are expressed as 1978 costs.

SUMDIP is an electricity cost summation and discount code. For each postulated electric plant in the DGE 1979-2000 hydrothermal electric development scenario, SUMDIP:

- (1) Checks the R&D impact year against the plant power-on-line year to determine if that plant will be affected by R&D results,
- (2) If so, calculate the total saving in electricity production cost for that plant,
- (3) Calculates the present value (1978) of the savings, and
- (4) Sums the present value across all prospects and years.

The final result, the present value of the summed cost savings across the 27 prospects and 22 years is the "estimated benefit" of the R&D subelement.

From the above discussion, it can be seen that the estimated benefit is sensitive to:

- (1) The magnitude of impacts of the R&D subelement on geothermal well drilling and electricity production technology,
- (2) The physical characteristics of the individual prospects,
- (3) The commercialization date for the R&D product,
- (4) The number and power-on-line years of plants in the DGE hydrothermal electric scenario.

3.0 BASELINE ASSUMPTIONS FOR THE ANALYSIS

The physical characteristics of the prospects to which the calculation are sensitive include: Reservoir temperature, Well depth, Rock hardness, and Brine salinity. The assumed values for these can be found in References 4 and 5, with the exception of certain updated values presented in Table B-2 and documented in Reference 3.

Table B-3 documents changes in baseline assumptions made by MITRE between the time when the GELCOM model was first prepared and documented (4) and the use of GELCOM as part of the present GEOBEN code. All other financial assumptions are as documented in Reference 4.

TABLE B-2

PROSPECT CHARACTERISTICS UPDATED DURING DEVELOPMENT OF THE WELCST MODEL

PROSPECT	CHARACTERISTIC	NEW ESTIMATE	OLD ESTIMATE
Geysers, CA	Rock Hardness	Medium-Hard	Medium
Raft River, ID	Rock Hardness	Medium	Soft
Chandler, AZ	Rock Hardness	Medium-Hard	Medium
East Mesa, CA	Well Depth	2.0 km	1.5 km
Heber, CA	Well Depth	2.0 km	1.5 km

TABLE B-3

DIFFERENCES IN BASELINE ASSUMPTIONS
BETWEEN GEOBEN (1978) AND GELCOM (1977)

PARAMETER	GEOBEN VALUE	GELCOM VALUE	REASON FOR REVISION
Net Investment Tax Credit*	12%	4%	National Energy Act of 1978.
Expensing of Intangible Drilling Costs (as % of Well Costs)	70%	0%	National Energy Act of 1978.
Electricity Price Escalation Rate	3%	5%	Reconsideration of recent public utility commissions' rulings.
Property Tax Rate	2%	1%	More recent data.
Well Lifetimes, (years)-			
. Low salinity resources	15	10	Recent estimates from industrial sources.
. High salinity resources	7.5	5	

* The percentage Investment Tax Credit on the entire plant cost that results from applying the 20% rate to the allowable components of the plant.

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