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Potential Impact of R&D on Hydrothermal Energy Cost

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Sandia National Laboratories
Albuquerque, New Mexico 87185 and Livermore, California 94550
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POTENTIAL IMPACT OF R&D ON HYDROTHERMAL ENERGY COST

(A Preliminary Application of IMGEO
to the DOE/GTD Technology Programs)

SAND--87-2409

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Department 6250
Sandia National Laboratories

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ABSTRACT

The potential impact of the DOE/Geothermal Technology Development programs on the cost of geothermal power has been estimated using the computer program IMGEO.300. Results indicate a potential 30-40% cost reduction for hydrothermal systems with a 40-50% cost reduction potential for binary systems.

The purpose of this document is to demonstrate the use of IMGEO. The initial results are tentative because the R&D goals have not been finalized and the code has not been completely validated.

POTENTIAL IMPACT OF R&D ON HYDROTHERMAL ENERGY COSTS

Introduction

One aid to define R&D directions is a sensitivity analysis which estimates the potential impacts of various research results on a product cost. To aid R&D planning in the DOE/Geothermal Technologies Division (GTD), Director J. E. Mock asked for such an analysis to be developed for planning R&D in the GTD technology areas of Reservoir Engineering, Hard Rock Penetration and Conversion Processes. A numerical model was developed for use in projecting the impact of R&D results on hydrothermal energy costs. The initial version of this model, IMGEO 300(1), is complete, available, and is currently being documented and further validated.

This paper briefly reviews the basis and limitations of that model, and applies the analysis to evaluate potential R&D impacts based on currently proposed GTD technology improvements. The purpose of this paper is demonstrate use of the analysis and solicit suggestions for improvement.

IMGEO - The Analysis Basis

This analysis evaluates potential first order effects of R&D technology improvements on the cost of geothermal energy. The analysis can be used by program managers and researchers as one tool for defining R&D directions. This analysis is not designed to provide an economic estimate of costs, but rather to compare potential R&D impacts on relative costs; i.e., an X% improvement in heat exchanger operation can decrease the cost of power from a binary plant by Y%. To meet the needs of the analysis and desires for its use, the following boundary conditions exist.

1. **Economics:** All economic factors are held constant at January 1, 1987 levels. (We want to isolate technology only and assume for this exercise that interest rates, inflation, etc., changes will not have a first order effect on relative costs).
2. **Generic Geothermal Fields:** The cost and quality of a geothermal resource is closely tied to the local geology. Five geologically distinct regions in the U.S. were selected for this analysis; the Imperial Valley, Basin and Range, Cascades, Geysers and young volcanics. These areas map into those evaluated in the USGS 726 Bulletin.⁽²⁾ All production facilities in a given region are considered to have the same well depths and costs, fluid chemistry and properties, conversion facilities and reservoir parameters.
3. **Risk:** Reduction of risk through improved reservoir analysis and process technology is quantified using procedures similar to those used by financial groups in funding geothermal development.⁽³⁾ In this analysis, the "worst case" is used to provide a cost and the worst case cost increment is included in the initial loan.
4. **Data Base:** Fundamental information gathered in many previous economic studies had been combined into an analysis by Meridian.⁽⁴⁾ This Meridian massive data base is used as the resource for this analysis.
5. **Validation:** The results of the analyses are consistent with published data and limited "expert interviews." Further review is in process.
6. **Expert Systems Analysis:** Consistent quantitative data is not available for many needed parameters, e.g., generic decline curves, ranges of solids content, uncertainty in H₂S levels, the amount of lost circulation encountered in drilling, etc. Consequently, "best" estimates or correlations were made using input from people experienced in those areas. The lack of time and

monies limited input in many areas and some estimates may need to be revised in the future. However, the information used is considered valid for this first order analysis.

R&D Goals

DOE program managers define the goals to provide direction and emphasis for the research. Overall program goals result in definition of projects; each project then has its own specific goals. For the purposes of this paper, only the overall program goals will be used.^(5,6) These goals are:

Reservoir Research	1. reduce reservoir measurement and future production uncertainties 50% by 1990.
Rock Penetration Mechanics	2. reduce overall well costs 20% by 1990 and 30% by 1992.
Conversion Technology	3. increase the efficiency of binary plants 28% over that of Heber by 1990.
	4. reduce O&M plant costs 8-15% by 1995.

Acknowledging that any goals will be controversial and these goals will be modified by new information, these were the basis for the following analysis to provide initial insight into the potential impact of GTD R&D and to solicit critique for improved R&D focus.

Analysis

IMGEO.300 was used to estimate the potential economic impact due to accomplishment of the four R&D goals just noted. Only the liquid-dominated

hydrothermal (not the geysers) resources were considered since those are the focus of the R&D. Calculations are detailed in the appendix.

Figure 1 projects the potential savings for all R&D on the tentative R&D schedule. The cost reduction potential of the GTD program is 30-40% if averaged over all hydrothermal systems (except dry steam).

A useful insight is the potential impact on individual regions in order to schedule R&D for a more timely impact on geothermal development. Figure 2 shows the results of the analyses of the combined impact of all technologies for each of the liquid-dominated geologic regions. Potential impact is greatest on the binary systems with possible savings of 40-50% projected. Such a reduction would make binary plants commercially competitive with other current energy resources.

Figure 3 depicts the results of an analysis comparing the impact of the three technology areas. This analysis assumes that all goals are met in 1995 (not the proposed schedule) in order to compare just the program elements.

Two points are worth noting from Figure 3. (1) The goals as now defined indicate a balanced program with Reservoir Research, Hard Rock Penetration and Conversion Technology each contributing about the same potential reduction in power costs. (2) The reduction due to improvements considered as a set is less than the reduction obtained by summing the improvements calculated independently for each Technology Program. This fact can be understood since the program areas are interrelated, e.g., a plant efficiency improvement will require fewer wells thereby decreasing the impact of well cost savings.

FIGURE 1
POTENTIAL REDUCTION IN COST OF POWER
PER R & D GOALS PROJECTIONS
(MULTI-REGION)

φ

FIGURE 2
POTENTIAL COST REDUCTION DUE TO R & D
BY REGION

FIGURE 3
RELATIVE POTENTIAL IMPACT OF GTD
TECHNOLOGY PROGRAMS
MULTI-REGION
(LINEAR ACHIEVEMENT OF GOALS FROM 1986-1995)

Summary and Conclusions

This study was an initial application of the IMGEO analysis to evaluate the potential impact of GTD Technology R&D programs on the cost of geothermal power. Results are most tentative because goals and schedules are being evolved and application procedures for IMGEO are still being developed.

Nevertheless, the analyses are useful in showing the following:

1. The technology R&D can have a significant impact; 30-40% cost reductions for the total hydrothermal resource and a 40-50% cost reduction potential for the binary systems.
2. Each of the Geothermal Technology Development Programs (Reservoir Research, Hard Rock Penetration and Conversion Technology) have the potential to contribute equally to power cost reduction.
3. Cost reductions estimated using achievements from combined programs are less than cost reductions estimated by summing individual program impacts because impacts of the individual programs are interdependent.
4. Analyses using IMGEO provides useful guidance to R&D planning and should be of benefit in prioritizing individual projects.

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1. Petty, S., D. Entingh and B. J. Livesay, IM-GEO, Impact of R&D on Cost of Geothermal Power. (Report in process)
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3. Future of Geothermal Energy, GRC Conference/San Diego, CA; November 24-25, 1986.
4. Entingh, D., Meridian Corporation's Geothermal Data Base includes GEO.BAS and BUSBAR which are used in this analysis, 1987.
5. Geothermal Technology Division Programmatic Goals and Objectives, Rough Draft, April 15, 1987.
6. Geothermal Progress Monitor No. 9, A Decade of Progress 1974-1984, US DOE/Asst. Sec'y for Conservation and Renewable Energy, 104 pp., May 1986.

APPENDICES

The following tables give the IMGEO.300 input and output for the previously presented data. Current distribution of costs and R&D impacts are given in the table. The proposed R&D improvements are listed below the table.

APPENDIX A

IMGEO RESULTS

Potential impact of meeting all the goals and schedules on power cost reduction. All liquid-dominated geothermal regions are included; weighted by the size of the region.

GEOHERMAL COST OF POWER ESTIMATE RUN: 09-10-1987 - 09:26:58 199D
Multi-Region Weighted Averaged Data WEIGHTS = Regional Capacity

[From IMGED Model] ACCOUNT	1986 TECHNOL. ***** % OF COST	***** NEW TECHNOLOGY SYSTEM *****		
		% OF 1986 TECHNOLOGY ELECT. COST	% COST CHANGE FROM 1986	% OF NEW TECH. TOTAL ELECT. COST
TOTAL :	100.0	75.8	- 24.2	100.0
RISK FRACTION :	32.2	19.3	- 40.2	25.4
1. Identify Reservoir	5.6	4.5	- 19.3	6.0
2. Confirm Reservoir	6.4	5.3	- 17.1	7.0
3. Wells	33.5	23.6	- 29.7	31.1
4. Downhole Pumps	1.4	0.8	- 39.8	1.1
5. Gathering Equip.	5.7	4.3	- 24.1	5.7
6. Power Plant	33.7	26.0	- 22.8	34.2
7. Heat Exchangers	4.1	2.7	- 35.5	3.5
8. Brine Stabilizing	2.0	2.0	- 0.0	2.6
9. Environmental	4.4	4.4	- 0.0	5.8
10. Insurance	3.2	2.3	- 29.6	3.0

IM-GEO: SENSITIVITY FACTORS IN EFFECT 09-10-1987 - 09:26:58

R&D Achvmt: TOTAL Cost, Avg. Well [Nom.=1.0]: 0.80
R&D Achvmt: O&M Cost, FLASH Plant [Nom.=1.0]: 0.92
R&D Achvmt: Efficiency, BINARY Plant [Nom.=1.0]: 1.28
R&D Achvmt: O&M Cost, BINARY Plant [Nom.=1.0]: 0.92

RISK: Wellhead Temperature, F [Nom.=1.0] : 0.50
RISK: Prod. Well Flow, Klb/hr [Nom.=1.0] : 0.50
RISK: Inject. Well Flow, Klb/hr [Nom.=1.0] : 0.50

Regional Weights = Regional Capacity

GEOHERMAL COST OF POWER ESTIMATE RUN: 09-10-1987 - 09:29:54 1991
Multi-Region Weighted Averaged Data WEIGHTS = Regional Capacity

[From IMGEO Model] ACCOUNT	1986 TECHNOL. ***** % OF COST	***** NEW TECHNOLOGY SYSTEM *****		
		% OF 1986 TECHNOLOGY ELECT. COST	% COST CHANGE FROM 1986	% OF NEW TECH. TOTAL ELECT. COST
TOTAL :	100.0	70.7	- 29.3	100.0
RISK FRACTION :	32.2	16.9	- 47.4	24.0
1. Identify Reservoir	5.6	4.5	- 19.7	6.4
2. Confirm Reservoir	6.4	5.3	- 17.1	7.5
3. Wells	33.5	20.0	- 40.3	28.3
4. Downhole Pumps	1.4	0.6	- 54.3	0.9
5. Gathering Equip.	5.7	3.7	- 34.3	5.3
6. Power Plant	33.7	25.5	- 24.4	36.0
7. Heat Exchangers	4.1	2.5	- 38.5	3.6
8. Brine Stabilizing	2.0	2.0	- 0.0	2.8
9. Environmental	4.4	4.4	- 0.0	6.2
10. Insurance	3.2	2.1	- 35.1	3.0

IM-GEO: SENSITIVITY FACTORS IN EFFECT 09-10-1987 - 09:29:54

R&D Achvmt: Flow Rate, Producer [Nom.=1.0]: 1.25
R&D Achvmt: Flow Rate, Injector [Nom.=1.0]: 1.25
R&D Achvmt: TOTAL Cost, Avg. Well [Nom.=1.0]: 0.80
R&D Achvmt: O&M Cost, FLASH Plant [Nom.=1.0]: 0.92
R&D Achvmt: Efficiency, BINARY Plant [Nom.=1.0]: 1.28
R&D Achvmt: O&M Cost, BINARY Plant [Nom.=1.0]: 0.92

RISK: Wellhead Temperature, F [Nom.=1.0] : 0.50
RISK: Prod. Well Flow, Klb/hr [Nom.=1.0] : 0.50
RISK: Inject. Well Flow, Klb/hr [Nom.=1.0] : 0.50

Regional Weights = Regional Capacity

GEOTHERMAL COST OF POWER ESTIMATE RUN: 09-10-1987 - 09:43:06 1992
Multi-Region Weighted Averaged Data WEIGHTS = Regional Capacity

[From IMGED Model] ACCOUNT	1986 TECHNOL. ***** % OF COST	***** NEW TECHNOLOGY SYSTEM *****		
		% OF 1986 TECHNOLOGY ELECT. COST	% COST CHANGE FROM 1986	% OF NEW TECH. TOTAL ELECT. COST
TOTAL :	100.0	67.7	- 32.3	100.0
RISK FRACTION :	32.2	16.0	- 50.4	23.6
1. Identify Reservoir	5.6	4.0	- 28.6	5.9
2. Confirm Reservoir	6.4	4.7	- 25.5	7.0
3. Wells	33.5	18.2	- 45.8	26.8
4. Downhole Pumps	1.4	0.6	- 54.3	0.9
5. Gathering Equip.	5.7	3.7	- 34.3	5.5
6. Power Plant	33.7	25.5	- 24.4	37.6
7. Heat Exchangers	4.1	2.5	- 38.5	3.8
8. Brine Stabilizing	2.0	2.0	- 0.0	3.0
9. Environmental	4.4	4.4	- 0.0	6.5
10. Insurance	3.2	2.0	- 37.6	3.0

IM-GE0: SENSITIVITY FACTORS IN EFFECT 09-10-1987 - 09:43:06

R&D Achvmt: Flow Rate, Producer [Nom.=1.0]: 1.25
R&D Achvmt: Flow Rate, Injector [Nom.=1.0]: 1.25
R&D Achvmt: TOTAL Cost, Avg. Well [Nom.=1.0]: 0.70
R&D Achvmt: O&M Cost, FLASH Plant [Nom.=1.0]: 0.92
R&D Achvmt: Efficiency, BINARY Plant [Nom.=1.0]: 1.28
R&D Achvmt: O&M Cost, BINARY Plant [Nom.=1.0]: 0.92

RISK: Wellhead Temperature, F [Nom.=1.0] : 0.50
RISK: Prod. Well Flow, Klb/hr [Nom.=1.0] : 0.50
RISK: Inject. Well Flow, Klb/hr [Nom.=1.0] : 0.50

Regional Weights = Regional Capacity

GEOHERMAL COST OF POWER ESTIMATE RUN: 09-10-1987 - 09:08:40 1985
Multi-Region Weighted Averaged Data WEIGHTS = Regional Capacity

[From IMGED Model] ACCOUNT	1986 TECHNOL. ***** % OF COST	***** NEW TECHNOLOGY SYSTEM *****		
		% OF 1986 TECHNOLOGY ELECT. COST	% COST CHANGE FROM 1986	% OF NEW TECH. TOTAL ELECT. COST
TOTAL :	100.0	67.3	- 32.7	100.0
RISK FRACTION :	32.2	16.0	- 50.5	23.7
1. Identify Reservoir	5.6	4.0	- 28.6	6.0
2. Confirm Reservoir	6.4	4.7	- 25.5	7.0
3. Wells	33.5	18.2	- 45.8	27.0
4. Downhole Pumps	1.4	0.6	- 54.3	0.9
5. Gathering Equip.	5.7	3.7	- 34.3	5.5
6. Power Plant	33.7	25.1	- 25.5	37.2
7. Heat Exchangers	4.1	2.5	- 38.5	3.8
8. Brine Stabilizing	2.0	2.0	- 0.0	3.0
9. Environmental	4.4	4.4	- 0.0	6.6
10. Insurance	3.2	2.0	- 37.6	3.0

IM-GEO: SENSITIVITY FACTORS IN EFFECT 09-10-1987 - 09:08:40

R&D Achvmt: Flow Rate, Producer [Nom.=1.0]: 1.25
R&D Achvmt: Flow Rate, Injector [Nom.=1.0]: 1.25
R&D Achvmt: TOTAL Cost, Avg. Well [Nom.=1.0]: 0.70
R&D Achvmt: O&M Cost, FLASH Plant [Nom.=1.0]: 0.85
R&D Achvmt: Efficiency, BINARY Plant [Nom.=1.0]: 1.28
R&D Achvmt: O&M Cost, BINARY Plant [Nom.=1.0]: 0.85

RISK: Wellhead Temperature, F [Nom.=1.0] : 0.50
RISK: Prod. Well Flow, Klb/hr [Nom.=1.0] : 0.50
RISK: Inject. Well Flow, Klb/hr [Nom.=1.0] : 0.50

Regional Weights = Regional Capacity

APPENDIX B

IMGEO RESULTS FOR FLASH AND BINARY R&D

The potential impact of R&D on both flash and binary energy extraction power costs were calculated using IMGEO.300 for each region. The results are given in the tables and the R&D achievements listed beneath the table.

GEOHERMAL COST OF POWER ESTIMATE
Region : 1 Imperial Valley - Flash

RUN: 09-10-1987 - 09:08:40 1995

[From IMGED Model] ACCOUNT	1986 TECHNOL. ***** % OF COST	***** NEW TECHNOLOGY SYSTEM *****		
		% OF 1986 TECHNOLOGY ELECT. COST	% COST CHANGE FROM 1986	% OF NEW TECH. TOTAL ELECT. COST
TOTAL :	100.0	82.1	- 17.9	100.0
RISK FRACTION :	31.4	22.8	- 27.3	27.8
1. Identify Reservoir	6.3	4.6	- 27.0	5.6
2. Confirm Reservoir	8.1	6.2	- 23.6	7.6
3. Wells	29.0	18.8	- 35.2	22.9
4. Downhole Pumps	0.0	0.0	- 0.0	0.0
5. Gathering Equip.	5.4	4.3	- 20.4	5.3
6. Power Plant	29.8	27.4	- 8.1	33.4
7. Heat Exchangers	0.0	0.0	- 0.0	0.0
8. Brine Stabilizing	7.2	7.2	- 0.0	8.8
9. Environmental	11.4	11.4	- 0.0	13.9
10. Insurance	2.7	2.2	- 20.9	2.6

IM-GEO: SENSITIVITY FACTORS IN EFFECT 09-10-1987 - 09:08:40

R&D Achvmt: Flow Rate, Producer [Nom.=1.0]: 1.25
R&D Achvmt: Flow Rate, Injector [Nom.=1.0]: 1.25
R&D Achvmt: TOTAL Cost, Avg. Well [Nom.=1.0]: 0.70
R&D Achvmt: O&M Cost, FLASH Plant [Nom.=1.0]: 0.85
R&D Achvmt: Efficiency, BINARY Plant [Nom.=1.0]: 1.28
R&D Achvmt: O&M Cost, BINARY Plant [Nom.=1.0]: 0.85

RISK: Wellhead Temperature, F [Nom.=1.0] : 0.50
RISK: Prod. Well Flow, Klb/hr [Nom.=1.0] : 0.50
RISK: Inject. Well Flow, Klb/hr [Nom.=1.0] : 0.50

Regional Weights = Regional Capacity

GEO THERMAL COST OF POWER ESTIMATE RUN: 09-10-1987 - 09:08:40 1915
 Region : 2 Imperial Valley - Binary

[From IMGEO Model] ACCOUNT	1986 TECHNOL. ***** % OF COST	***** NEW TECHNOLOGY SYSTEM *****		
		% OF 1986 TECHNOLOGY ELECT. COST	% COST CHANGE FROM 1986	% OF NEW TECH. TOTAL ELECT. COST
TOTAL :	100.0	59.4	- 40.6	100.0
RISK FRACTION :	26.2	8.2	- 68.8	13.8
1. Identify Reservoir	5.9	4.2	- 28.7	7.1
2. Confirm Reservoir	6.2	4.7	- 24.2	7.9
3. Wells	21.4	8.8	- 58.9	14.8
4. Downhole Pumps	2.9	1.3	- 52.8	2.3
5. Gathering Equip.	7.6	4.0	- 47.4	6.7
6. Power Plant	42.3	27.6	- 34.7	46.4
7. Heat Exchangers	10.1	6.8	- 33.1	11.4
8. Brine Stabilizing	0.0	0.0	- 0.0	0.0
9. Environmental	0.0	0.0	- 0.0	0.0
10. Insurance	3.7	2.0	- 45.0	3.4

IM-GEO: SENSITIVITY FACTORS IN EFFECT 09-10-1987 - 09:08:40

R&D Achvmt: Flow Rate, Producer [Nom.=1.0]: 1.25
 R&D Achvmt: Flow Rate, Injector [Nom.=1.0]: 1.25
 R&D Achvmt: TOTAL Cost, Avg. Well [Nom.=1.0]: 0.70
 R&D Achvmt: O&M Cost, FLASH Plant [Nom.=1.0]: 0.85
 R&D Achvmt: Efficiency, BINARY Plant [Nom.=1.0]: 1.28
 R&D Achvmt: O&M Cost, BINARY Plant [Nom.=1.0]: 0.85

 RISK: Wellhead Temperature, F [Nom.=1.0] : 0.50
 RISK: Prod. Well Flow, Klb/hr [Nom.=1.0] : 0.50
 RISK: Inject. Well Flow, Klb/hr [Nom.=1.0] : 0.50

Regional Weights = Regional Capacity

GEOHERMAL COST OF POWER ESTIMATE
Region : 3 Basin & Range - Flash

RUN: 09-10-1987 - 09:44:50 1995

[From IMGEO Model] ACCOUNT	1986 TECHNOL. ***** % OF COST	***** NEW TECHNOLOGY SYSTEM *****		
		% OF 1986 TECHNOLOGY ELECT. COST	% COST CHANGE FROM 1986	% OF NEW TECH. TOTAL ELECT. COST
TOTAL :	100.0	74.6	- 25.4	100.0
RISK FRACTION :	20.0	5.1	- 74.7	6.8
1. Identify Reservoir	11.1	8.1	- 27.3	10.8
2. Confirm Reservoir	12.5	9.3	- 25.4	12.5
3. Wells	26.0	13.4	- 48.4	18.0
4. Downhole Pumps	0.0	0.0	- 0.0	0.0
5. Gathering Equip.	5.7	4.3	- 25.5	5.7
6. Power Plant	41.6	37.3	- 10.1	50.1
7. Heat Exchangers	0.0	0.0	- 0.0	0.0
8. Brine Stabilizing	0.0	0.0	- 0.0	0.0
9. Environmental	0.0	0.0	- 0.0	0.0
10. Insurance	3.1	2.1	- 32.0	2.9

IM-GEO: SENSITIVITY FACTORS IN EFFECT 09-10-1987 - 09:44:50

R&D Achvmt: Flow Rate, Producer [Nom.=1.0]: 1.25
R&D Achvmt: Flow Rate, Injector [Nom.=1.0]: 1.25
R&D Achvmt: TOTAL Cost, Avg. Well [Nom.=1.0]: 0.70
R&D Achvmt: O&M Cost, FLASH Plant [Nom.=1.0]: 0.85
R&D Achvmt: Efficiency, BINARY Plant [Nom.=1.0]: 1.28
R&D Achvmt: O&M Cost, BINARY Plant [Nom.=1.0]: 0.85

RISK: Wellhead Temperature, F [Nom.=1.0] : 0.50
RISK: Prod. Well Flow, Klb/hr [Nom.=1.0] : 0.50
RISK: Inject. Well Flow, Klb/hr [Nom.=1.0] : 0.50

Regional Weights = Regional Capacity

GEOHERMAL COST OF POWER ESTIMATE
Region : 4 Basin & Range - Binary

RUN: 09-10-1987 - 09:44:50 1995

[From IMGED Model] ACCOUNT	1986 TECHNOL. ***** % OF COST	***** NEW TECHNOLOGY SYSTEM *****		
		% OF 1986 TECHNOLOGY ELECT. COST	% COST CHANGE FROM 1986	% OF NEW TECH. TOTAL ELECT. COST
TOTAL :	100.0	52.2	- 47.8	100.0
RISK FRACTION :	31.4	8.1	- 74.2	15.5
1. Identify Reservoir	2.3	1.6	- 32.7	3.0
2. Confirm Reservoir	2.2	1.7	- 24.0	3.2
3. Wells	28.4	10.4	- 63.3	19.9
4. Downhole Pumps	4.3	2.0	- 53.5	3.8
5. Gathering Equip.	6.2	2.5	- 59.2	4.8
6. Power Plant	42.7	25.8	- 39.5	49.5
7. Heat Exchangers	10.2	6.3	- 38.1	12.1
8. Brine Stabilizing	0.0	0.0	- 0.0	0.0
9. Environmental	0.0	0.0	- 0.0	0.0
10. Insurance	3.7	1.9	- 50.1	3.6

IM-GEO: SENSITIVITY FACTORS IN EFFECT 09-10-1987 - 09:44:50

R&D Achvmt: Flow Rate, Producer [Nom.=1.0]: 1.25
R&D Achvmt: Flow Rate, Injector [Nom.=1.0]: 1.25
R&D Achvmt: TOTAL Cost, Avg. Well [Nom.=1.0]: 0.70
R&D Achvmt: O&M Cost, FLASH Plant [Nom.=1.0]: 0.85
R&D Achvmt: Efficiency, BINARY Plant [Nom.=1.0]: 1.28
R&D Achvmt: O&M Cost, BINARY Plant [Nom.=1.0]: 0.85

RISK: Wellhead Temperature, F [Nom.=1.0] : 0.50
RISK: Prod. Well Flow, Klb/hr [Nom.=1.0] : 0.50
RISK: Inject. Well Flow, Klb/hr [Nom.=1.0] : 0.50

Regional Weights = Regional Capacity

GEOHERMAL COST OF POWER ESTIMATE
Region : 5 Cascades - Flash

RUN: 09-10-1987 - 09:44:50 1985

[From IMGED Model] ACCOUNT	1986 TECHNOL. ***** % OF COST	***** NEW TECHNOLOGY SYSTEM *****		
		% OF 1986 TECHNOLOGY ELECT. COST	% COST CHANGE FROM 1986	% OF NEW TECH. TOTAL ELECT. COST
TOTAL :	100.0	67.9	- 32.1	100.0
RISK FRACTION :	34.1	17.3	- 49.4	25.4
1. Identify Reservoir	7.5	5.4	- 27.8	8.0
2. Confirm Reservoir	8.9	6.5	- 26.7	9.6
3. Wells	48.8	27.8	- 43.2	40.9
4. Downhole Pumps	0.0	0.0	- 0.0	0.0
5. Gathering Equip.	6.2	4.9	- 20.4	7.3
6. Power Plant	24.6	20.9	- 15.3	30.7
7. Heat Exchangers	0.0	0.0	- 0.0	0.0
8. Brine Stabilizing	0.0	0.0	- 0.0	0.0
9. Environmental	0.0	0.0	- 0.0	0.0
10. Insurance	3.9	2.4	- 38.5	3.5

IM-GED: SENSITIVITY FACTORS IN EFFECT 09-10-1987 - 09:44:50

R&D Achvmt: Flow Rate, Producer [Nom.=1.0]: 1.25
R&D Achvmt: Flow Rate, Injector [Nom.=1.0]: 1.25
R&D Achvmt: TOTAL Cost, Avg. Well [Nom.=1.0]: 0.70
R&D Achvmt: O&M Cost, FLASH Plant [Nom.=1.0]: 0.85
R&D Achvmt: Efficiency, BINARY Plant [Nom.=1.0]: 1.28
R&D Achvmt: O&M Cost, BINARY Plant [Nom.=1.0]: 0.85

RISK: Wellhead Temperature, F [Nom.=1.0] : 0.50
RISK: Prod. Well Flow, Klb/hr [Nom.=1.0] : 0.50
RISK: Inject. Well Flow, Klb/hr [Nom.=1.0] : 0.50

Regional Weights = Regional Capacity

GEOTHERMAL COST OF POWER ESTIMATE
Region : 6 Cascades - Binary

RUN: 09-10-1987 - 09:44:50 1995

[From IMGED Model] ACCOUNT	1986 TECHNOL. ***** % OF COST	***** NEW TECHNOLOGY SYSTEM *****		
		% OF 1986 TECHNOLOGY ELECT. COST	% COST CHANGE FROM 1986	% OF NEW TECH. TOTAL ELECT. COST
TOTAL :	100.0	54.4	- 45.6	100.0
RISK FRACTION :	25.4	6.1	- 76.0	11.2
1. Identify Reservoir	2.6	1.7	- 34.3	3.1
2. Confirm Reservoir	2.3	1.7	- 25.1	3.2
3. Wells	18.9	7.3	- 61.6	13.4
4. Downhole Pumps	4.0	1.8	- 54.8	3.3
5. Gathering Equip.	5.1	2.2	- 56.6	4.1
6. Power Plant	50.9	30.2	- 40.8	55.5
7. Heat Exchangers	12.2	7.4	- 39.4	13.6
8. Brine Stabilizing	0.0	0.0	- 0.0	0.0
9. Environmental	0.0	0.0	- 0.0	0.0
10. Insurance	4.0	2.1	- 47.7	3.8

IM-GE0: SENSITIVITY FACTORS IN EFFECT 09-10-1987 - 09:44:50

R&D Achvmt: Flow Rate, Producer [Nom.=1.0]: 1.25
R&D Achvmt: Flow Rate, Injector [Nom.=1.0]: 1.25
R&D Achvmt: TOTAL Cost, Avg. Well [Nom.=1.0]: 0.70
R&D Achvmt: O&M Cost, FLASH Plant [Nom.=1.0]: 0.85
R&D Achvmt: Efficiency, BINARY Plant [Nom.=1.0]: 1.28
R&D Achvmt: O&M Cost, BINARY Plant [Nom.=1.0]: 0.85

RISK: Wellhead Temperature, F [Nom.=1.0] : 0.50
RISK: Prod. Well Flow, Klb/hr [Nom.=1.0] : 0.50
RISK: Inject. Well Flow, Klb/hr [Nom.=1.0] : 0.50

Regional Weights = Regional Capacity

GEOHERMAL COST OF POWER ESTIMATE
Region : 7 Young Volcanics - Flash 1

RUN: 09-10-1987 - 09:44:50 1995

[From IMGED Model] ACCOUNT	1986 TECHNOL. ***** % OF COST	***** NEW TECHNOLOGY SYSTEM *****		
		% OF 1986 TECHNOLOGY ELECT. COST	% COST CHANGE FROM 1986	% OF NEW TECH. TOTAL ELECT. COST
TOTAL :	100.0	69.2	- 30.8	100.0
RISK FRACTION :	45.2	24.9	- 44.9	36.0
1. Identify Reservoir	6.5	4.7	- 28.5	6.7
2. Confirm Reservoir	7.1	5.1	- 27.4	7.4
3. Wells	56.3	32.3	- 42.6	46.7
4. Downhole Pumps	0.0	0.0	- 0.0	0.0
5. Gathering Equip.	5.5	3.9	- 27.8	5.7
6. Power Plant	14.3	13.4	- 6.3	19.3
7. Heat Exchangers	0.0	0.0	- 0.0	0.0
8. Brine Stabilizing	1.8	1.8	- 0.0	2.6
9. Environmental	6.5	6.5	- 0.0	9.5
10. Insurance	2.0	1.4	- 30.7	2.0

IM-GED: SENSITIVITY FACTORS IN EFFECT 09-10-1987 - 09:44:50

R&D Achvmt: Flow Rate, Producer [Nom.=1.0]: 1.25
R&D Achvmt: Flow Rate, Injector [Nom.=1.0]: 1.25
R&D Achvmt: TOTAL Cost, Avg. Well [Nom.=1.0]: 0.70
R&D Achvmt: O&M Cost, FLASH Plant [Nom.=1.0]: 0.85
R&D Achvmt: Efficiency, BINARY Plant [Nom.=1.0]: 1.28
R&D Achvmt: O&M Cost, BINARY Plant [Nom.=1.0]: 0.85

RISK: Wellhead Temperature, F [Nom.=1.0] : 0.50
RISK: Prod. Well Flow, Klb/hr [Nom.=1.0] : 0.50
RISK: Inject. Well Flow, Klb/hr [Nom.=1.0] : 0.50

Regional Weights = Regional Capacity

-31-32

GEOHERMAL COST OF POWER ESTIMATE

RUN: 09-10-1987 - 09:44:50 1995

Region : 8 Young Volcanics - Flash 2

[From IMGED Model] ACCOUNT	1986 TECHNOL. ***** % OF COST	***** NEW TECHNOLOGY SYSTEM *****		
		% OF 1986 TECHNOLOGY ELECT. COST	% COST CHANGE FROM 1986	% OF NEW TECH. TOTAL ELECT. COST
TOTAL :	100.0	83.0	- 17.0	100.0
RISK FRACTION :	31.6	24.5	- 22.4	29.5
1. Identify Reservoir	7.8	5.7	- 27.0	6.9
2. Confirm Reservoir	8.9	6.7	- 24.8	8.1
3. Wells	18.5	11.6	- 37.4	14.0
4. Downhole Pumps	0.0	0.0	- 0.0	0.0
5. Gathering Equip.	5.6	4.6	- 17.8	5.6
6. Power Plant	36.3	32.2	- 11.4	38.7
7. Heat Exchangers	0.0	0.0	- 0.0	0.0
8. Brine Stabilizing	4.6	4.6	- 0.0	5.5
9. Environmental	15.3	15.3	- 0.0	18.5
10. Insurance	2.9	2.3	- 21.3	2.7

IM-GEO: SENSITIVITY FACTORS IN EFFECT

09-10-1987 - 09:44:50

R&D Achvmt: Flow Rate, Producer [Nom.=1.0]: 1.25
 R&D Achvmt: Flow Rate, Injector [Nom.=1.0]: 1.25
 R&D Achvmt: TOTAL Cost, Avg. Well [Nom.=1.0]: 0.70
 R&D Achvmt: O&M Cost, FLASH Plant [Nom.=1.0]: 0.85
 R&D Achvmt: Efficiency, BINARY Plant [Nom.=1.0]: 1.28
 R&D Achvmt: O&M Cost, BINARY Plant [Nom.=1.0]: 0.85

RISK: Wellhead Temperature, F [Nom.=1.0] : 0.50
 RISK: Prod. Well Flow, Klb/hr [Nom.=1.0] : 0.50
 RISK: Inject. Well Flow, Klb/hr [Nom.=1.0] : 0.50

Regional Weights = Regional Capacity

APPENDIX C

IMGEO RESULTS BY TECHNOLOGY

Each of the technologies (Reservoir Research, Conversion Technology and Hard Rock Penetration) were evaluated for potential cost impact. Each technology was applied independently to a multi-region resource. Results are shown in the tables and the R&D achievement assumptions are listed below. The last calculation includes all of the achievements simultaneously to indicate the interactions between individual programs.

GEOHERMAL COST OF POWER ESTIMATE RUN: 09-10-1987 - 14:13:42
Multi-Region Weighted Averaged Data WEIGHTS = Regional Capacity

[From IMGED Model] ACCOUNT	1986 TECHNOL. ***** % OF COST	***** NEW TECHNOLOGY SYSTEM *****		
		% OF 1986 TECHNOLOGY ELECT. COST	% COST CHANGE FROM 1986	% OF NEW TECH. TOTAL ELECT. COST
TOTAL :	100.0	85.3	- 14.7	100.0
RISK FRACTION :	32.2	17.5	- 45.7	20.5
1. Identify Reservoir	5.6	5.6	- 1.1	6.5
2. Confirm Reservoir	6.4	6.3	- 0.5	7.4
3. Wells	33.5	24.7	- 26.4	29.0
4. Downhole Pumps	1.4	1.1	- 18.4	1.3
5. Gathering Equip.	5.7	4.1	- 27.6	4.8
6. Power Plant	33.7	30.6	- 9.1	35.9
7. Heat Exchangers	4.1	3.7	- 11.3	4.3
8. Brine Stabilizing	2.0	2.0	- 0.0	2.3
9. Environmental	4.4	4.4	- 0.0	5.2
10. Insurance	3.2	2.8	- 13.8	3.3

IM-GEO: SENSITIVITY FACTORS IN EFFECT 09-10-1987 - 14:13:42

RISK: Reservoir Satur. Temp, F [Nom.=1.0] : 0.50
RISK: Wellhead Temperature, F [Nom.=1.0] : 0.50
RISK: H2S, PPM [Nom.=1.0] : 0.50
RISK: Tot. Dis. Solids, PPK [Nom.=1.0] : 0.50
RISK: Prod. Well Flow, Klb/hr [Nom.=1.0] : 0.50
RISK: Inject. Well Flow, Klb/hr [Nom.=1.0] : 0.50
RISK: Decline Coeff., 1/Years [Nom.=1.0] : 0.50

Regional Weights = Regional Capacity

Hard Rock Penetration

GEOHERMAL COST OF POWER ESTIMATE RUN: 09-10-1987 - 14:18:08
Multi-Region Weighted Averaged Data WEIGHTS = Regional Capacity

[From IMGED Model] ACCOUNT	1986 TECHNDL. ***** % OF COST	***** NEW TECHNOLOGY SYSTEM ***** % OF 1986 % COST % OF NEW TECHNOLOGY CHANGE TECH. TOTAL ELECT. COST FROM 1986 ELECT. COST		
TOTAL :	100.0	84.9	- 15.1	100.0
RISK FRACTION :	32.2	25.4	- 21.2	29.9
1. Identify Reservoir	5.6	4.5	- 20.7	5.2
2. Confirm Reservoir	6.4	5.2	- 18.7	6.1
3. Wells	33.5	24.1	- 28.1	28.4
4. Downhole Pumps	1.4	1.0	- 25.8	1.2
5. Gathering Equip.	5.7	4.8	- 15.3	5.6
6. Power Plant	33.7	32.4	- 3.7	38.2
7. Heat Exchangers	4.1	3.8	- 7.2	4.5
8. Brine Stabilizing	2.0	2.0	- 0.0	2.4
9. Environmental	4.4	4.4	- 0.0	5.2
10. Insurance	3.2	2.7	- 16.7	3.2

IM-GED: SENSITIVITY FACTORS IN EFFECT 09-10-1987 - 14:18:08

R&D Achvmt: Flow Rate, Producer [Nom.=1.0]: 1.25
R&D Achvmt: Flow Rate, Injector [Nom.=1.0]: 1.25
R&D Achvmt: Well Prblms, Lost Circul [Nom.=1.0]: 0.80
R&D Achvmt: Well Prblms, Cementing [Nom.=1.0]: 0.80
R&D Achvmt: TOTAL Cost, Avg. Well [Nom.=1.0]: 0.80
R&D Achvmt: Workover Interval, Prod. [Nom.=1.0]: 1.20
R&D Achvmt: Workover Interval, Injc. [Nom.=1.0]: 1.20

Regional Weights = Regional Capacity

Conversion Technologies

GEOHERMAL COST OF POWER ESTIMATE RUN: 09-10-1987 - 14:21:32
Multi-Region Weighted Averaged Data WEIGHTS = Regional Capacity

[From IMGED Model] ACCOUNT	1986 TECHNOL. ***** % OF COST	***** NEW TECHNOLOGY SYSTEM *****		
		% OF 1986 TECHNOLOGY ELECT. COST	% COST CHANGE FROM 1986	% OF NEW TECH. TOTAL ELECT. COST
TOTAL :	100.0	88.8	- 11.2	100.0
RISK FRACTION :	32.2	28.6	- 11.3	32.2
1. Identify Reservoir	5.6	5.6	- 0.8	6.3
2. Confirm Reservoir	6.4	6.4	- 0.2	7.2
3. Wells	33.5	31.4	- 6.2	35.4
4. Downhole Pumps	1.4	1.0	- 27.6	1.1
5. Gathering Equip.	5.7	5.0	- 12.0	5.6
6. Power Plant	33.7	27.9	- 17.0	31.5
7. Heat Exchangers	4.1	2.8	- 31.1	3.2
8. Brine Stabilizing	2.0	2.0	- 2.6	2.2
9. Environmental	4.4	3.9	- 11.4	4.4
10. Insurance	3.2	2.8	- 12.4	3.2

IM-GEO: SENSITIVITY FACTORS IN EFFECT 09-10-1987 - 14:21:32

R&D Achvmt: O&M Cost, FLASH Plant [Nom.=1.0]: 0.85
R&D Achvmt: Efficiency, BINARY Plant [Nom.=1.0]: 1.28
R&D Achvmt: O&M Cost, BINARY Plant [Nom.=1.0]: 0.85
R&D Achvmt: O&M Cost, Heat Exchange [Nom.=1.0]: 0.85
R&D Achvmt: O&M Cost, Brine Stabil. [Nom.=1.0]: 0.85
R&D Achvmt: O&M Cost, H2S Treatment [Nom.=1.0]: 0.85

Regional Weights = Regional Capacity

Combined Technologies

GEOTHERMAL COST OF POWER ESTIMATE		RUN: 09-10-1987 - 14:28:17			
Multi-Region Weighted Averaged Data		WEIGHTS = Regional Capacity			
[From IMGEO Model]	1986	***** NEW TECHNOLOGY SYSTEM *****			
	TECHNOL.	% OF 1986	% COST	% OF NEW	
ACCOUNT	*****	TECHNOLOGY	CHANGE	TECH. TOTAL	
	% OF COST	ELECT. COST	FROM 1986	ELECT. COST	
TOTAL :	100.0	65.7	- 34.3	100.0	
RISK FRACTION :	32.2	13.0	- 59.7	19.8	
1. Identify Reservoir	5.6	4.4	- 21.9	6.7	
2. Confirm Reservoir	6.4	5.1	- 19.3	7.8	
3. Wells	33.5	16.9	- 49.6	25.7	
4. Downhole Pumps	1.4	0.6	- 54.8	1.0	
5. Gathering Equip.	5.7	3.2	- 43.2	4.9	
6. Power Plant	33.7	25.1	- 25.5	38.2	
7. Heat Exchangers	4.1	2.4	- 41.0	3.7	
8. Brine Stabilizing	2.0	2.0	- 2.6	3.0	
9. Environmental	4.4	3.9	- 11.4	5.9	
10. Insurance	3.2	2.1	- 35.8	3.2	

IM-GEO: SENSITIVITY FACTORS IN EFFECT 09-10-1987 - 14:28:17

R&D Achvmt: Flow Rate, Producer	[Nom.=1.0]:	1.25
R&D Achvmt: Flow Rate, Injector	[Nom.=1.0]:	1.25
R&D Achvmt: Well Prblms, Lost Circul	[Nom.=1.0]:	0.80
R&D Achvmt: Well Prblms, Cementing	[Nom.=1.0]:	0.80
R&D Achvmt: TOTAL Cost, Avg. Well	[Nom.=1.0]:	0.80
R&D Achvmt: Workover Interval, Prod.	[Nom.=1.0]:	1.20
R&D Achvmt: Workover Interval, Injc.	[Nom.=1.0]:	1.20
R&D Achvmt: O&M Cost, FLASH Plant	[Nom.=1.0]:	0.85
R&D Achvmt: Efficiency, BINARY Plant	[Nom.=1.0]:	1.28
R&D Achvmt: O&M Cost, BINARY Plant	[Nom.=1.0]:	0.85
R&D Achvmt: O&M Cost, Heat Exchange	[Nom.=1.0]:	0.85
R&D Achvmt: O&M Cost, Brine Stabil.	[Nom.=1.0]:	0.85
R&D Achvmt: O&M Cost, H2S Treatment	[Nom.=1.0]:	0.85
RISK: Reservoir Satur. Temp, F	[Nom.=1.0]	: 0.50
RISK: Wellhead Temperature, F	[Nom.=1.0]	: 0.50
RISK: H2S, PPM	[Nom.=1.0]	: 0.50
RISK: Tot. Dis. Solids, PPK	[Nom.=1.0]	: 0.50
RISK: Prod. Well Flow, Klb/hr	[Nom.=1.0]	: 0.50
RISK: Inject. Well Flow, Klb/hr	[Nom.=1.0]	: 0.50
RISK: Decline Coeff., 1/Years	[Nom.=1.0]	: 0.50

Regional Weights = Regional Capacity

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