HRI 7912

A MANPOWER ASSESSMENT
OF THE GEOTHERMAL INDUSTRY

(Draft Copy)

Human Resources Institute
University of Utah
Salt Lake City, Utah

August 24, 1979

DISCLAIMER

DISCLAIMER

A MANPOWER ASSESSMENT

OF THE GEOTHERMAL INDUSTRY

(Draft Copy)

Human Resources Institute
University of Utah
Salt Lake City, Utah

August 24, 1979

TABLE OF CONTENTS

Table of Contents, Cont.

Table of Contents, Cont.

Table of Contents, Cont.

OVERVIEW

I-1

Purpose of Project

In order to develop a more complete picture of the magnitude of manpower involvement and manpower needs of industries associated with energy production the Department of Energy has funded a number of manpower assessment projects. The Human Resources Institute at the University of Utah was requested by the Division of Manpower Assessment -- Department of Energy to conduct a manpower assessment of the geothermal industry which is to be used as a component in developing a national information system on energy related manpower. The specific purposes of this project were to conduct a base line estimate of the manpower involved in the industry, to determine if there is a likely shortage of particular skills, and to forecast future employment in the geothermal industry.

Summary

Mail Survey

During 1978, 1527 public and private organizations were surveyed to determine if they had any employment in geothermal activities during 1977. This number represented what we considered to be the potential universe of government agencies, educational institutions, and private firms. However, 421 of these organizations responded that they were not involved in the geothermal industry in 1977. Of the remainder the postal service was unable to deliver 122 mailings, 463 were nonrespondents, and of the 521 that indicated they were involved in the industry 448 provided manpower estimates of which 307 were in the private sector.

Geothermal manpower is highly concentrated in the industry. The twenty largest employers responding to the mail survey accounted for 52.02 percent of the total estimated manpower in our survey. In the

I

private sector the fourteen largest firms accounted for 50 percent of the measured employment.

Research and development activities involved 25.8 percent of all measured manpower in the mail survey. The highest concentration of R & D manpower (13.1% of the total) is in the resource exploration and assessment activity, which itself accounts for nearly one third of all estimated employment.

The ratios of geothermal to total employment for the different types of organizations were quite low. In other words geothermal activities are generally peripheral to other major activities for most of the organizations. The text contains discussion on the problems with such a measure, but it is significant to note that the ratio in the private sector is only .23 percent.

As a second part of the mail survey we compiled another mailing list from the initial respondents which received another questionnaire designed to gain more occupationally specific information. The most interesting result from this mailing was that 59.3 percent of all employment measured in the final survey was in the scientist and engineers occupational category.

Personal Interviews

The main purposes of the personal interview phase were to seek out information on current or potential occupational bottlenecks and on particular manpower requirements for bringing a power plant on line. Thirty-five firms were interviewed from October of 1978 through February of 1979.

There was substantial evidence of scarcities of geologists, geophysicists, reservoir engineers, environmental engineers, and drill rig personnel. Drill rig personnel appeared to be a problem because of the undesirable characteristics of the job, but the others were viewed as in short supply because of strong demands on a national level. There did not appear to be specific occupations which were viewed as unique to the geothermal industry. The current trend is for modification of existing skills and orientation to the unique characteristics of the geothermal resource.

The occupational profiles and forecasting information gathered in the personal interviews formed the basis for the forecasting model. In some areas the information was not complete and other sources were relied upon.

Manpower Forecast

Since direct use activities in the industry are extremely undefined, we have based our forecast on the more identifiable segment of the industry which is concerned with electrical energy production. The basis for the forecast is the electrial energy output as projected in the Interagency Geothermal Coordinating Council's 1979 Annual Report. Our approach was to construct what we believe to be the minimum and maximum requirements for bringing a standardized 50 MW_e power plant on line and then to apply these requirements to the IGCC's scenario. The use of a standardized power plant was necessary since it is highly speculative to assume that manpower requirements thus far experienced will apply to other development sites because of the heterogeneous character of the geothermal resource. The following figures summarize the forecasting results first for employment which will be attached directly to activities for commercial production of electricity and second for the additional employment that will be generated in the industry which is not directly connected with site-specific activities (e.g., research and development and legal services) or is related to site-specific activities other than commercial electrical energy production (e.g., space heating).

Employment Resulting Directly from Commercial Electrical Energy Production

Net Employment Gains	Minimum	Maximum
1980 - 1985 (new hires)	11,802	32,339
1986 - 1990 (new hires)	37,073	101,482
1980 - 1990 (new hires)	48,875	133,821

All Other Employment Which Is Not for Commercial Electrical Production Directly Related to Site-Specific Developments As Defined in the Forecasting Model

Net Employment Gains	Minimum	Maximum
1980 - 1985 (new hires)	18,883	51,742
1986 - 1990 (new hires)	59,317	162,371
1980 - 1990 (new hires)	78,200	214,114

We have also forecasted the manpower requirements for each occupational category. These are presented on pages I-6 through I-12. Note that these occupations are a mixture of manpower requirements at the development site and for supporting services. It was necessary to present the requirements in this manner because of the nature of the information which we were supplied, especially in the personal interview phase.

Technology Assessment

The Delphi technique was used in conducting this part of the study during 1978. The essential conclusion is that technology must advance in several areas in order to expand utilization of the resource. The basic impetus at this point seems to be in demonstrating commercial feasibility by small demonstration plants and in concentrating on lowering drilling costs. However, our results did not indicate an air of optimism for highly significant breakthroughs but rather pointed toward a slow but steady advance. Therefore, it does not appear that an unanticipated surge in manpower demand will result from rapid application of new technology.

Conclusions

The geothermal industry can be quite aptly described as an infant industry in a developed economy. It has been characterized by a large number of institutional, technological, and market uncertainties. But there is still a small segment of the industry which is well established because of long-term involvement at development sites in California (especially at The Geysers in Northern California and at Imperial Valley in Southern California) and this segment forms a rather stable core of continuous activity.

Most of the remainder of the industry is composed of firms of all sizes which are only marginally attached. Many of these firms are also

RESOURCE EXPLORATION AND ASSESSMENT

	Summed Total of Individuals from Surveyed Firms and Project Independence	Forecasting Coefficient (percent)	Derived New Employment Estimated from Forecasted Growth 1980-1985 min	1980-1985 max	1986-1990 min	1986-1990 max	1980-1990 min	1980-1990 max
Scientists/Engineers								
Geologist	32	3.61	427	1167	1338	3664	1764	4831
Geophysicist	43	4.86	574	1572	1802	4932	2375	6504
Geochemist	5	.56	67	181	208	568	274	749
Mechanial Engineer	2	.23	27	74	85	233	112	308
Drilling Engineer	2	.23	27	74	85	233	112	308
Petroleum Engineer	1	.11	13	37	42	116	56	154
Subtotal	85							
Administrative Management/Clerical Subtotal	11	1.24	147	401	460	1258	606	1659
Specialized Management								
Contracting/Purchasing	1	.11	13	37	42	116	56	154
Financial Analyst	1	.11	13	37	42	116	56	154
Accounting	3	.34	40	110	126	345	166	455
Legal	4	.45	53	146	167	457	220	602
Land Management	11	1.24	147	401	460	1258	606	1659
Subtotal	20							
Technicians								
Engineering Technician	1	.11	13	37	42	116	56	154
Computer Analyst	2	.23	27	74	85	233	112	308
Data Processing	1	.11	13	37	42	116	56	154
Draftsman	9	1.02	120	330	378	1035	499	1365
Exploration Technician	6	.68	80	220	252	690	332	910
Environmental Technician	10	1.13	133	365	419	1147	552	1512
Subtotal	29							
Others								
Laborers	4	.45	53	146	167	457	220	602
Truck Drivers	2	.23	27	74	85	233	112	308
Subtotal	6							
Total	151							

DRILLING

	Summed Total of Individuals from Surveyed Firms and Project Independence	Forecasting Coefficient (percent)	Derived New Employment Estimated from Forecasted Growth 1980-1985 min	1980-1985 max	1986-1990 min	1986-1990 max	1980-1990 min	1980-1990 max
Job Foreman	13	1.47	173	475	545	1492	718	1967
Drilling Foreman	13	1.47	173	475	545	1492	718	1967
Driller	24	2.71	320	876	1005	2750	1325	3627
Derrickman (Asst. Driller)	29	3.28	387	1061	1216	3329	1603	4389
Motorman	4	.45	53	146	167	457	220	602
Pipefitter	4	.45	53	146	167	457	220	602
Welder	2	.23	27	74	85	233	112	308
Crane Operator	1	.11	13	37	42	116	56	154
Truck Driver	2	.23	27	74	85	233	112	308
Laborer	12	1.36	160	440	504	1380	665	1820
Total	104							

RESERVOIR FEED SYSTEM (Construction)

	Estimate from Project Independence	Forecasting Coefficient (percent)	Derived New Employment Estimated from Forecasted Growth 1980-1985 min	1980-1985 max	1986-1990 min	1986-1990 max	1980-1990 min	1980-1990 max
Scientists/Engineers								
Mechanical Engineer	2	.23	27	74	85	233	112	308
Civil Engineer	2	.23	27	74	85	233	112	308
Subtotal	4							
Technicians								
Draftsman	2	.23	27	74	85	233	112	308
Route Surveyor	5	.56	67	181	208	568	274	749
Subtotal	7							
Field Supervision/Inspection								
Foreman	2	.23	27	74	85	233	112	308
Inspector	3	.34	40	110	126	345	166	455
Subtotal	5							
Skilled Labor								
Welder	4	.45	53	146	167	457	220	602
Carpenter	2	.23	27	74	85	233	112	308
Concrete Worker	4	.45	53	146	167	457	220	602
Dozer Operator	2	.23	27	74	85	233	112	308
Crane Operator	2	.23	27	74	85	233	112	308
Insulation Installer	6	.68	80	220	252	690	332	910
Subtotal	20							
Other								
Truck Driver	4	.45	53	146	167	457	220	602
Subtotal	4							
Total	40							

41

RESERVIOR FEED SYSTEM (operation/maintenance)

	Estimate from Project Independence	Forecasting Coefficient (percent)	Derived New Employment Estimated from Forecasted Growth 1980-1985 min	1980-1985 max	1986-1990 min	1986-1990 max	1980-1990 min	1980-1990 max
Field Operator	2	.23	27	74	85	233	112	308
Foreman	1	.11	13	37	42	116	56	154
Pipefitter	2	.23	27	74	85	233	112	308
Welder	1	.11	13	37	42	116	56	154
Insulation Installer	2	.23	27	74	85	233	112	308
Crane Operator	1	.11	13	37	42	116	56	154
Total	9							

CONSTRUCTION OF POWER PLANTS

	Summed Total of Individuals from Surveyed Firms and Project Independence	Forecasting Coefficient (percent)	Derived New Employment Estimated from Forecasted Growth 1980-1985 min	1980-1985 max	1986-1990 min	1986-1990 max	1980-1990 min	1980-1990 max
Scientists/Engineers								
Structural Engineer	11	1.24	147	401	460	1258	606	1659
Mechanical Engineer	21	2.37	280	766	879	2405	1158	3172
Civil Engineer	12	1.36	160	440	504	1380	665	1820
Electrical Engineer	19	2.15	253	695	797	2182	1051	2877
Corrosion Engineer	1	.11	13	37	42	116	56	154
Processing Engineer	3	.34	40	110	126	345	166	455
Drilling Engineer	1	.11	13	37	42	116	56	154
Geological Engineer	1	.11	13	37	42	116	56	154
Reservoir Engineer	1	.11	13	37	42	116	56	154
Architect	5	.56	67	181	208	568	274	749
Archeologist	1	.11	13	37	42	116	56	154
Geologist	8	.90	107	291	334	913	440	1204
Subtotal	84							
Administrative Management/Clerical Subtotal	34							
Specialized Management								
Procurement Specialist	2	.23	27	74	85	233	112	308
Land Management	1	.11	13	37	42	116	56	154
Lawyer	3	.34	40	110	126	345	166	455
Comptroller	27	3.05	360	986	1131	3095	1491	4082
Subtotal	33							
Technicians								
Draftsman	22	2.49	293	805	923	2527	1217	3332
Surveyor	8	.90	107	291	334	913	440	1204
Instrument Technician	4	.45	53	146	167	457	220	602
Pipeline Technican	3	.34	40	110	126	345	166	455
Air Quality Technician	1	.11	13	37	42	116	56	154
Noise Pollution Technican	1	.11	13	37	42	116	56	154
Technical Assistant	3	.34	40	110	126	345	166	455

CONSTRUCTION OF POWER PLANTS CONDT

Field Supervision/Inspection								
Construction Superintendent	2	.23	27	74	85	233	112	308
Foreman	3	.34	40	110	126	345	166	455
Inspectors	17	1.92	227	621	712	1948	938	2569
Subtotal	22							
Skilled Labor								
Electrician	21	2.37	280	766	879	2405	1158	3172
Pipefitter	15	1.69	200	547	627	1715	826	2262
Welder	8	.90	107	291	334	913	440	1204
Millwright	8	.90	107	291	334	913	440	1204
Machinist	2	.23	27	74	85	233	112	308
Ironworker	16	1.81	213	585	671	1836	885	2422
Rigger	8	.90	107	291	334	913	440	1204
Concrete Worker	15	1.69	200	547	627	1715	826	2262
Sheetmetal Worker	6	.68	80	220	252	690	332	910
Carpenter	60	6.78	800	2192	2514	6880	3314	9073
Plumber	4	.45	53	146	167	457	220	602
Insulation Installer	4	.45	53	146	167	457	220	602
Tile Setter	2	.23	27	74	85	233	112	308
Painter	4	.45	53	146	167	457	220	602
Crane Operator	4	.45	53	146	167	457	220	602
Pile Driver	4	.45	53	146	167	457	220	602
Boilermaker	2	.23	27	74	85	233	112	308
Equipment Operator	27	3.05	360	986	1131	3095	1491	482
Subtotal	210							
Others								
Teamsters	13	1.47	173	475	545	1492	718	1967
Toolpushers	2	.23	27	74	85	233	112	308
Contract Support People	2	.23	27	74	85	233	112	308
Common Laborers	42	4.75	560	1536	1761	4820	2322	6356
Drilling Head	1	.11	13	37	42	116	56	154
Warehouseman	3	.34	40	110	126	345	166	455
Subtotal	63							
Total	488							

OPERATION AND MAINTENANCE OF POWER PLANT

	Summed Total of Individuals from Surveyed Firms and Project Independence	Forecasting Coefficient (percent)	Derived New Employment Estimated from Forecasted Growth 1980-1985 min	1980-1985 max	1986-1990 min	1986-1990 max	1980-1990 min	1980-1990 max
Scientists/Engineers								
Mechanical Engineer	1	.11	13	37	42	116	56	154
Corrosion Engineer	1	.11	13	37	42	116	56	154
Subtotal	2							
Technicians								
Senior Power Plant Operator	2	.23	27	74	85	233	112	308
Power Plant Operator	21	2.37	280	766	879	2405	1158	3172
Asst. Power Plant Operator	4	.45	53	146	167	457	220	602
Control Technician	1	.11	13	37	42	116	56	154
Instrument Technician	6	.68	80	220	252	690	332	910
Subtotal	34							
Supervisory Personnel								
Plant Superintendent	1	.11	13	37	42	116	56	154
Shift Foreman	3	.34	40	110	126	345	166	455
Foreman	2	.23	27	74	85	233	112	308
Subtotal	6							
Skilled Labor								
Millwright	4	.45	53	146	167	457	220	602
Machinist	13	1.47	173	475	545	1492	718	1967
Pipefitter	3	.34	40	110	126	345	166	455
Welder	4	.45	53	146	167	457	220	602
Electrician	11	1.24	147	401	460	1258	606	1659
Insulation Installer	2	.23	27	74	85	233	112	308
Painter	2	.23	27	74	85	233	112	308
Rigger	5	.56	67	181	208	568	274	749
Crane Operator	1	.11	13	37	42	116	56	154
Subtotal	45							
Other								
Laborer — Subtotal	6							
Total	93							

highly active in other energy industries, and in some cases the larger ones have the capability of creating a separate geothermal staff as needed.

The attachment of manpower to the industry can be described in the same way as the firms. This has made a base line assessment quite difficult. For example, a drilling firm may be working in the geothermal industry one month and in the petroleum industry the next. This mobility of labor and capital resources has been desirable since the industry is not yet mature enough to support on a continuing basis the large number of peripheral firms which have thus far become only marginally attached to it.

Even if the industry achieves the maximum employment growth discussed in our forecast, the national impact will be relatively minimal. This may be even more true if the full-time-equivalent of new hires is composed of a much larger number of part-time or part-year employees who are also involved in a number of activities other than geothermal. However, it is important to note that the high concentration of scientists and engineers in the industry will certainly contribute to scarcities of this type of manpower at the national level.

We forsee only two areas of major long-term local impact. One is at The Geysers in Northern California, but development there has taken place over two years and will continue to do so in such a manner that major labor shortages are not likely. The other is at Imperial Valley in Southern California, but this development too will be slow and allow ample time for appropriate planning. This has already taken place with socio-economic impact studies having been conducted at this area.

Recommendations

Specific

Evidence from different parts of our study point out that the most serious manpower problems that are likely to emerge in the industry are in certain scientific and engineering occupations. Firms point out that they can not effectively compete in the national market because they must absorb the costs of training and/or orienting new recruits to the special characteristics of the geothermal industry. Underlying this problem is the fact that there are few universities that offer any courses in the geothermal area, as compared to the considerable higher education training available which is geared toward the oil and gas industries. The probable reason for this lack of courses is a perception of low demand for this type of expertise and/or the unlikely prospect for rapid and widespread growth of the geothermal industry.

We recommend that the federal government consider financial support to expand the number of geothermal courses offered at a few universities located in the western states. The reason for this recommendation is that the federal government is in a better position to gage geothermal manpower needs at the national level. Also, such a relatively modest action at this time would help ensure a training base which could expand as the industry grows thus avoiding any "crisis" type of actions in the future if the industry does enter a phase of unexpected rapid expansion. A full degree offering does not appear desirable because the basics are general to many scientific and engineering areas. By being able to draw from a pool of college trained manpower that has alread been oriented to the industry and has received special training courses, geothermal industry employers should be in a more competitive position for recruiting relative to other energy industries.

Because of the small size of the geothermal industry and because of the likelihood that its size relative to other energy industries will not be dramatically altered in the next ten years, no other recommendations specific to geothermal manpower are made. Other problems that will emerge are associated with remote site developments. But these are of a short-term duration, and thus far the large firms involved in bringing power plants on line have demonstrated an ability to transfer skilled labor and other personnel as needed.

General

We have attempted to define some of the manpower characteristics of a relatively new industry. But it is virtually impossible to grasp the evolutionary character of the industry in terms of changing occupational growth patterns with a one-time study. We recommend that a mail survey conducted periodically (perhaps at two year intervals) would help define the changing nature of the industry and the manpower structure which consequently evolves. This could be done at minimal cost since the information base is now well established.

Another way to try to develop a rationalized manpower information system in the energy industries is to examine the several industries that already exist in various stages of development. That is, with coal, oil, gas, nuclear, geothermal, and solar we have energy industries ranging from the well established to the novel. It would be a useful policy tool to examine the occupational structure in these industries at various stages of development in order to determine common trends. With the numerous studies that have been done over the years sufficient documentation probably already exists for this type of study. We believe such a study would be a significant step forward in developing a conceptual framework upon which future manpower studies can receive much guidance. It should also be helpful in forseeing changes which empirically oriented studies do not anticipate. Finally, it would allow policymakers to draw upon a synthesis of past studies in order to more accurately define areas of needed research and to develop a general manpower information system.

RESOURCE EXPLORATION AND ASSESSMENT

	Summed Total of Individuals from Surveyed Firms and Project Independence	Forecasting Coefficient (percent)	Derived New Employment Estimated from Forecasted Growth 1980-1985 min	1980-1985 max	1986-1990 min	1986-1990 max	1980-1990 min	1980-1990 max
Scientists/Engineers								
Geologist	32	3.61	427	1167	1338	3664	1764	4831
Geophysicist	43	4.86	574	1572	1802	4932	2375	6504
Geochemist	5	.56	67	181	208	568	274	749
Mechanial Engineer	2	.23	27	74	85	233	112	308
Drilling Engineer	2	.23	27	74	85	233	112	308
Petroleum Engineer	1	.11	13	37	42	116	56	154
Subtotal	85							
Administrative Management/Clerical Subtotal	11	1.24	147	401	460	1258	606	1659
Specialized Management								
Contracting/Purchasing	1	.11	13	37	42	116	56	154
Financial Analyst	1	.11	13	37	42	116	56	154
Accounting	3	.34	40	110	126	345	166	455
Legal	4	.45	53	146	167	457	220	602
Land Management	11	1.24	147	401	460	1258	606	1659
Subtotal	20							
Technicians								
Engineering Technician	1	.11	13	37	42	116	56	154
Computer Analyst	2	.23	27	74	85	233	112	308
Data Processing	1	.11	13	37	42	116	56	154
Draftsman	9	1.02	120	330	378	1035	499	1365
Exploration Technician	6	.68	80	220	252	690	332	910
Environmental Technician	10	1.13	133	365	419	1147	552	1512
Subtotal	29							
Others								
Laborers	4	.45	53	146	167	457	220	602
Truck Drivers	2	.23	27	74	85	233	112	308
Subtotal	6							
Total	151							

DRILLING

	Summed Total of Individuals from Surveyed Firms and Project Independence	Forecasting Coefficient (percent)	Derived New Employment Estimated from Forecasted Growth 1980-1985 min	1980-1985 max	1986-1990 min	1986-1990 max	1980-1990 min	1980-1990 max
Job Foreman	13	1.47	173	475	545	1492	718	1967
Drilling Foreman	13	1.47	173	475	545	1492	718	1967
Driller	24	2.71	320	876	1005	2750	1325	3627
Derrickman (Asst. Driller)	29	3.28	387	1061	1216	3329	1603	4389
Motorman	4	.45	53	146	167	457	220	602
Pipefitter	4	.45	53	146	167	457	220	602
Welder	2	.23	27	74	85	233	112	308
Crane Operator	1	.11	13	37	42	116	56	154
Truck Driver	2	.23	27	74	85	233	112	308
Laborer	12	1.36	160	440	504	1380	665	1820
Total	104							

RESERVOIR FEED SYSTEM (Construction)

	Estimate from Project Independence	Forecasting Coefficient (percent)	Derived New Employment Estimated from Forecasted Growth 1980-1985 min	1980-1985 max	1986-1990 min	1986-1990 max	1980-1990 min	1980-1990 max
Scientists/Engineers								
Mechanical Engineer	2	.23	27	74	85	233	112	308
Civil Engineer	2	.23	27	74	85	233	112	308
Subtotal	4							
Technicians								
Draftsman	2	.23	27	74	85	233	112	308
Route Surveyor	5	.56	67	181	208	568	274	749
Subtotal	7							
Field Supervision/Inspection								
Foreman	2	.23	27	74	85	233	112	308
Inspector	3	.34	40	110	126	345	166	455
Subtotal	5							
Skilled Labor								
Welder	4	.45	53	146	167	457	220	602
Carpenter	2	.23	27	74	85	233	112	308
Concrete Worker	4	.45	53	146	167	457	220	602
Dozer Operator	2	.23	27	74	85	233	112	308
Crane Operator	2	.23	27	74	85	233	112	308
Insulation Installer	6	.68	80	220	252	690	332	910
Subtotal	20							
Other								
Truck Driver	4	.45	53	146	167	457	220	602
Subtotal	4							
Total	40							

RESERVIOR FEED SYSTEM (operation/maintenance)

	Estimate from Project Independence	Forecasting Coefficient (percent)	Derived New Employment Estimated from Forecasted Growth 1980-1985		1986-1990		1980-1990	
			min	max	min	max	min	max
Field Operator	2	.23	27	74	85	233	112	308
Foreman	1	.11	13	37	42	116	56	154
Pipefitter	2	.23	27	74	85	233	112	308
Welder	1	.11	13	37	42	116	56	154
Insulation Installer	2	.23	27	74	85	233	112	308
Crane Operator	1	.11	13	37	42	116	56	154
Total	9							

CONSTRUCTION OF POWER PLANTS

	Summed Total of Individuals from Surveyed Firms and Project Independence	Forecasting Coefficient (percent)	Derived New Employment Estimated from Forecasted Growth 1980-1985 min	1980-1985 max	1986-1990 min	1986-1990 max	1980-1990 min	1980-1990 max
Scientists/Engineers								
Structural Engineer	11	1.24	147	401	460	1258	606	1659
Mechanical Engineer	21	2.37	280	766	879	2405	1158	3172
Civil Engineer	12	1.36	160	440	504	1380	665	1820
Electrical Engineer	19	2.15	253	695	797	2182	1051	2877
Corrosion Engineer	1	.11	13	37	42	116	56	154
Processing Engineer	3	.34	40	110	126	345	166	455
Drilling Engineer	1	.11	13	37	42	116	56	154
Geological Engineer	1	.11	13	37	42	116	56	154
Reservoir Engineer	1	.11	13	37	42	116	56	154
Architect	5	.56	67	181	208	568	274	749
Archeologist	1	.11	13	37	42	116	56	154
Geologist	8	.90	107	291	334	913	440	1204
Subtotal	84							
Administrative Management/Clerical Subtotal	34							
Specialized Management								
Procurement Specialist	2	.23	27	74	85	233	112	308
Land Management	1	.11	13	37	42	116	56	154
Lawyer	3	.34	40	110	126	345	166	455
Comptroller	27	3.05	360	986	1131	3095	1491	4082
Subtotal	33							
Technicians								
Draftsman	22	2.49	293	805	923	2527	1217	3332
Surveyor	8	.90	107	291	334	913	440	1204
Instrument Technician	4	.45	53	146	167	457	220	602
Pipeline Technican	3	.34	40	110	126	345	166	455
Air Quality Technician	1	.11	13	37	42	116	56	154
Noise Pollution Technican	1	.11	13	37	42	116	56	154
Technical Assistant	3	.34	40	110	126	345	166	455

CONSTRUCTION OF POWER PLANTS CONDT

Field Supervision/Inspection								
Construction Superintendent	2	.23	27	74	85	233	112	308
Foreman	3	.34	40	110	126	345	166	455
Inspectors	17	1.92	227	621	712	1948	938	2569
Subtotal	22							
Skilled Labor								
Electrician	21	2.37	280	766	879	2405	1158	3172
Pipefitter	15	1.69	200	547	627	1715	826	2262
Welder	8	.90	107	291	334	913	440	1204
Millwright	8	.90	107	291	334	913	440	1204
Machinist	2	.23	27	74	85	233	112	308
Ironworker	16	1.81	213	585	671	1836	885	2422
Rigger	8	.90	107	291	334	913	440	1204
Concrete Worker	15	1.69	200	547	627	1715	826	2262
Sheetmetal Worker	6	.68	80	220	252	690	332	910
Carpenter	60	6.78	800	2192	2514	6880	3314	9073
Plumber	4	.45	53	146	167	457	220	602
Insulation Installer	4	.45	53	146	167	457	220	602
Tile Setter	2	.23	27	74	85	233	112	308
Painter	4	.45	53	146	167	457	220	602
Crane Operator	4	.45	53	146	167	457	220	602
Pile Driver	4	.45	53	146	167	457	220	602
Boilermaker	2	.23	27	74	85	233	112	308
Equipment Operator	27	3.05	360	986	1131	3095	1491	482
Subtotal	210							
Others								
Teamsters	13	1.47	173	475	545	1492	718	1967
Toolpushers	2	.23	27	74	85	233	112	308
Contract Support People	2	.23	27	74	85	233	112	308
Common Laborers	42	4.75	560	1536	1761	4820	2322	6356
Drilling Head	1	.11	13	37	42	116	56	154
Warehouseman	3	.34	40	110	126	345	166	455
Subtotal	63							
Total	488							

OPERATION AND MAINTENANCE OF POWER PLANT

	Summed Total of Individuals from Surveyed Firms and Project Independence	Forecasting Coefficient (percent)	Derived New Employment Estimated from Forecasted Growth 1980-1985 min	1980-1985 max	1986-1990 min	1986-1990 max	1980-1990 min	1980-1990 max
Scientists/Engineers								
Mechanical Engineer	1	.11	13	37	42	116	56	154
Corrosion Engineer	1	.11	13	37	42	116	56	154
Subtotal	2							
Technicians								
Senior Power Plant Operator	2	.23	27	74	85	233	112	308
Power Plant Operator	21	2.37	280	766	879	2405	1158	3172
Asst. Power Plant Operator	4	.45	53	146	167	457	220	602
Control Technician	1	.11	13	37	42	116	56	154
Instrument Technician	6	.68	80	220	252	690	332	910
Subtotal	34							
Supervisory Personnel								
Plant Superintendent	1	.11	13	37	42	116	56	154
Shift Foreman	3	.34	40	110	126	345	166	455
Foreman	2	.23	27	74	85	233	112	308
Subtotal	6							
Skilled Labor								
Millwright	4	.45	53	146	167	457	220	602
Machinist	13	1.47	173	475	545	1492	718	1967
Pipefitter	3	.34	40	110	126	345	166	455
Welder	4	.45	53	146	167	457	220	602
Electrician	11	1.24	147	401	460	1258	606	1659
Insulation Installer	2	.23	27	74	85	233	112	308
Painter	2	.23	27	74	85	233	112	308
Rigger	5	.56	67	181	208	568	274	749
Crane Operator	1	.11	13	37	42	116	56	154
Subtotal	45							
Other								
Laborer — Subtotal	6							
Total	93							

RESULTS FROM MAIL SURVEYS

Introduction

This phase of our study consisted of three initial mailings, a final mailing, and follow-up mailings for each category. The cover letters and questionnaires which were used are included as Appendix II-A. The results from the initial mailing will be discussed first.

Initial Questionnaire Mailings

Purpose

This investigation was designed to provide the bulk of information necessary for a baseline (1977) estimate of employment in the geothermal industry. Data was sought concerning person months of geothermal employment by activity from each organization. Additionally requested information was: (1) whether or not the firm was engaged in geothermal activities in 1977, (2) whether or not the firm was willing to participate in the final survey and if so, (3) who the appropriate contact person should be, and (4) the name of contractors who performed work for the organization totalling $25,000 or more in 1977.

With the above information we could then select the firms which were considered important for the personal interview phase, and all remaining firms (designated as in the industry and willing to participate further) were included in the final mail survey. Another goal was to develop a clearer picture of the number of organizations (especially in the private sector) actively involved in the industry since many geothermal references, directories, and other sources are likely to list observors as well as participants in the industry.

Procedure

The objective was to survey all organizations (private and public) which were known to be involved or potentially involved in the geothermal industry. The bulk of the mailing list was compiled from such sources as the Geothermal Resources Council's Geothermal Registry and the Geothermal World Directory (1977/78 Edition), which is published by Geothermal World Publications. Other sources were the list of the Department of Energy's geothermal related contracts, the contractors listed by organizations responding to the questionnaire, and information conveyed by personal contact with industry participants.

Because more organizations were becoming known to us through continuing efforts, three separate initial mailings were necessary. These took place in February, July, and October 1978. In each case a follow-up request was made to the nonrespondents from one to two months after the first mailing. Table II-1 gives a partial breakdown of these results.

Results

The findings in this part of our study provide the best overall picture of manpower involvement in the geothermal industry by the various types of activities. Given the large number of ways in which the data can be cross-classified, we have elected not to make every conceiveable comparison but instead to point out descriptively the most important and interesting comparisons.

Responses by Mailing Category

In relation to Table II-1 we believe the large number of mailings which the postal service was unable to deliver is indicative of the considerable

TABLE II-1

Initial Mailings[1]

	Total Mailed	Initial Response	Follow-up Mailing	Follow-up Response
1st	873	392 (plus 37 nondeliverables)	431	220 (plus 7 nondeliverables)
2nd	512	157 (plus 67 nondeliverables)	288	87 (plus 6 nondeliverables)
3rd	142	63 (plus 5 nondeliverables)	74	23 (no nondeliverables)
Total	1527	662 (plus 109 nondeliverables)	743	279 (plus 13 nondeliverables)

[1]Table includes additional responses generated due to phone contact (counted as follow-up responses). Also, nondeliverables who were subsequently contacted and responded were counted either as a first mailing or a follow-up response, depending on which category they were first listed as nondeliverable.

movement of organizations into and out of the industry. As might be expected, this is especially true in the private sector which accounts for 94.8 percent of the nondeliverables. In addition all of the 13 nondeliverables among our follow-up requests were in the private sector. Note that the nondeliverables are not double counted. That is, of the 13 none were returned to us as nondeliverables in the first mailing request. Hence, they automatically received follow-up requests and only then were they returned as nondeliverables, their location or status apparently having changed drastically in the interim.

After the first two mailings, which comprised 90.7 percent of the three groups of initial mailings, a phone survey was made of the nonrespondents (to the initial and follow-up requests) to find out: (1) if the memo had been received; (2) if not, was the organization involved in geothermal activity during 1977 and would a response be made to an additional questionnaire mailing; (3) if the questionnaire was received, what was the reason for nonresponse; and (4) if the information was available, could it be conveyed over the phone.

During August and September we attempted to contact the 268 organizations from the first mailing which had not responded to our initial and follow-up mailings in order to solicit reasons for nonresponse. Of this total, a phone listing could not be found for 66 organizations, 78 were not responsive to phone contact (i.e., not answering, not returning messages, etc.), 47 responded that they were not involved in the industry, 66 requested that the questionnaire be mailed to them again, and 11 gave manpower estimates over the phone. These results are incorporated into the mail results in the following manner. The 66 organizations for which a phone listing could not be found and the 78 which were not responsive to phone contact remained in the nonresponse category. Of the 66 which requested that the questionnaire be mailed to them again the respondents were coded and tabulated in the appropriate categories with all other respondents. The 47 nonindustry respondents and the eleven respondents which provided manpower estimates are counted as mail reqpondents, and the discussion in the rest of this part of the study incorporates this information.

Table II-2 shows the response rates (combining initial and follow-up responses) for the three mailings and the response rate for all the mailings together. As will be noted later, all respondents did not provide useful data and this forms the basis for further disaggregation. Also note that the data presented in Tables II-1 and II-2 and elsewhere in this part of the study have been checked for duplication and other errors. This was a difficult task, especially in the private sector. One basic criterion was to count different mailing addresses as different organizations. This approach was not completely satisfactory in many cases, and many organizations had to be contacted by phone to clear up ambiguities. Considering our efforts in this area, we are confident that our data are an accurate description of the industry with a minimum of error.

It should also be noted that the design of the questionnaire was changed for the second and third initial mailings. This was necessary because it was extremely difficult to pair the manpower involvement with a reasonable number of particular activities given the design of the questionnaire used in the first initial mailing. Information gained from the first mailing result was used to redesign the questionnaire into matrix form. The risk perceived with this format was that the complicated appearance of the questionniare would significantly reduce the response rate. Though the response rate did drop somewhat in the second and third mailings (Table II-2),

TABLE II-2

Response Rates[1]

Individual Mailings	Response Rate[1]	Response Rate[2]
1	612 ÷ 873 = 70.1%	612 ÷ 829 = 73.8%
2	244 ÷ 512 = 47.7%	244 ÷ 439 - 55.6%
3	86 ÷ 142 = 60.6%	86 ÷ 137 = 62.8%
Combined Response Rates	942 ÷ 1527 = 61.7%	942 ÷ 1405 = 67.0%

[1] Includes the nondeliverables in the denominator.

[2] Excludes the nondeliverables from the denominator.

we believe that benefit gained in the increased precision of response more than compensated for the drop in the response rates. That is, very few organizations used "other" in their response rather than a specifically designated cell in the matrix. Also, part of the drop in the response rates for the second and third mailings probably can be attributed to the use of less reliable resources in compiling the respective mailing lists.

Responses by Organizational Type

The 1527 questionnaires mailed are categorized as follows by the type of organization. Note that all nonprofit or other types of organizations that could not be strictly categorized as a government agency or educational institution were included in the private sector. Tables II-3 and II-4 present categorization of responses and response rates by organizational type.

Private firm or individual	1215	(79.6%)
State or local government	88	(5.8%)
Federal government	70	(4.6%)
Educational	+ 154	(10.0%)
Total	1527	

Industry vs. Nonindustry Responses

Of the 1527 organizations surveyed 521 (or 34.1%) indicated that they were involved in the industry in 1977, and 421 (or 27.6%) indicated that they were not involved in the industry during 1977. Including nondeliverables (122) these three categories total 1064. No information of any kind was forthcoming from the remaining 463 from either mail or phone contact.

TABLE II-3

Responses by Organizational Type

	Total Mailed	Initial Response	Follow-up Mailing	Follow-up Response
Private firm or individual	1215	489 (plus 102 nondeliverables)	658	217 (plus 13 nondeliverables)
State or local government	88	53 (plus 3 nondeliverables)	32	18 (no nondeliverables)
Federal government	70	39 (plus 2 nondeliverables)	29	14 (no nondeliverables)
Educational	154	78 (plus 2 nondeliverables)	74	34 (no nondeliverables)

TABLE II-4

Response Rates by Organizational Type[1]

	Response Rate[2]	Response Rate[3]
Private firm or individual	705 ÷ 1215 = 58.1%	705 ÷ 1087 = 64.9%
State or local government	71 ÷ 88 = 80.7%	71 ÷ 85 = 83.5%
Federal government	53 ÷ 70 = 75.7%	53 ÷ 68 = 77.9%
Educational	113 ÷ 154 = 73.3%	113 ÷ 152 = 74.3%
Combined Response Rate	942 ÷ 1527 = 61.7%	942 ÷ 1392 = 67.7%

[1] Includes the total of initial and follow-up responses from all three initial mailings.

[2] Includes nondeliverables in the denominator

[3] Excludes nondeliverables from denominator.

It can be seen from Table II-5 that the core of useful information in this phase of our study will be derived from a subset of the 521 organizations which responded that they were actively involved in the geothermal industry in 1977. This subset consists of 451 organizations which provided manpower estimates which could be coded for analysis.

Manpower Data By Organizational Type

There were a variety of reasons why organizations responded that they were in the industry but did not provide manpower estimates. In many cases they simply checked off an activity of involvement without designating a quantity of manpower. Other organizations replied that they were not in the geothermal industry in 1977 but either had been involved in earlier years or were planning involvement in the future. Still others responded that the requested information could not be provided because of proprietary reasons or because they viewed the request as too burdensome. As was previously mentioned, seventy organizations were in this category, for the reasons mentioned above and other less general reasons. This leaves 448 organizations which provided manpower estimates by specific activities for 1977.

There are a variety of ways in which this information may be cross-referenced for discussion. We will start by discussing all organizations taken together and then discuss the separate groups of organizations. The presentation of the distribution of manpower involvement by activity will follow in the next section.

The range of employment by organization in the industry was from 2725 person months to one person month (All quantities greater than .5

TABLE II-5

Industry and Nonindustry Responses by Organizational Type

	Industry[1]	Nonindustry[1]	Industry[2]	Nonindustry[2]
Private firm or individual	359 (23.5%)	346 (22.7%)	(25.6%)	(24.7%)
State or local government	48 (3.1%)	23 (1.5%)	(3.4%)	(1.6%)
Federal government	40 (2.6%)	13 (0.9%)	(2.8%)	(0.9%)
Educational	74 (4.8%)	39 (2.5%)	(5.3%)	(2.8%)
Total	521 (34.0%)	421 (27.6%)	(36.6%)	(26.9%)

[1]With nondeliverables included in denominator (e.g., 359 ÷ 1527 = 23.5%

[2]With nondeliverables excluded from denominator (e.g., 359 ÷ 1405 = 25.6%

were rounded to one). With all organizational types taken together the top twenty organizations account for 52.02 percent of all person months measured in the survey. Of these the federal government accounted for 13.48 percent of the total, educational institutions accounted for 3.31 percent of the total, and the private sector accounted for 35.23 percent of the total. The following figures lend more perspective to the degree of concentration.

Number of Organizations	Percent of Total Measured Manpower
21	≥ 1
19	≥ .5 and < 1
8	≥ .4 and < .5
11	≥ .3 and < .4
30	≥ .2 and < .3
79	≥ .1 and < .2
280	< .1

As was pointed out earlier, there was considerable difficulty in avoiding duplication of data from the same organization at different addresses or even different organizations at the same address. The basic criterion was to count different mailing addresses as different organizations, but this was considerably modified as various cases warranted. This method appears to have worked best for the category of private firm or individual, with the 307 respondents providing manpower estimates probably being a slight overestimate of the actual number of firms.[1]

We were also able to determine that most of the educational

[1] The term, private individual, in most cases means a consultant,

institutions responding were various academic departments or special research institutions. Therefore, the number of organizations responding in this category will also tend to be a slight overestimate since more than one department or research institution could have been surveyed from a single university or other institute of higher education. Also, our survey in this area was dominated by colleges with four year degree programs and graduate programs.

The complex and varied structures of government at the state and local levels introduces a greater degree of uncertainty as to whether or not we successfully avoided duplication of data. However, when questions arose, we attempted to ascertain the right answers by recontacting the respondents by telephone.

The problem in surveying organizations in the federal government was not so much the avoidance of duplication but at what level the data should be aggregated. For example, whenever it appeared that we were surveying a large number of field offices (e.g., for the U.S.G.S.), we attempted to go to the highest level in the organization that would have the needed information centrally located for all its field offices. The following data demonstrates that this method of aggregation considerably increases the "size" of the government organizations which were being surveyed.

	Number of Organizations Providing Employment Data	Mean	Median
All organizational types	448	75.28	20.00
Private firm or individual	307	76.71	20.00
State or local government	39	19.74	12.00
Federal government	33	170.17	30.00
Education	69	56.52	22.5

Despite the uncertainties introduced in the above discussion we believe that uncertainty is minimized in the most important area, the private sector. However, our manpower data provides only a static picture of what appears to be a rather dynamic industry in terms of entry and exit of firms. Although hard evidence was only spotty, (as indicated in our personal interview phase and correspondence with past and potential industry participants), it seems that the profit incentive coupled with a perception of industry stability (which in turn was dependent on solutions to institutional problems) is the driving force behind this movement.

Private Firms and Individuals

The range of employment in the private sector was from 2400 person months to one person month (All quantities greater than .5 were rounded to one). In this category the top twenty firms accounted for 57.18 percent of employment in the private sector, and just over half the employment, 50.19 percent, is derived from only eighteen firms. The distribution in the rest of the private sector is as follows.

Number of firms	Percent of manpower in the Private Sector
20	≥ 1
22	≥ .5 and < 1
9	≥ .4 and < .5
17	≥ .3 and < .4
21	≥ .2 and < .3
53	≥ .1 and < .2
165	< .1

Of the 310 firms providing estimates, 193 have 12 person months or more (i.e., the full-time equivalent of one person per year or more). We believe this in part illustrates the low degree of attachment of many firms and individuals to the industry. Many of the largest employers also are not engaged in the industry as a primary activity but have created separate geothermal departments which in many cases represent only a small portion of the firm's total employment.

State and Local Governments

The 40 organizations responding in this category were concentrated in the western states. Because of the lack of uniformity of government structure at these levels, especially in the leasing, environmental, and regulatory activities, it is probable that our survey did not include some agencies. We did attempt to survey all agencies that could be directly identified with geothermal activities. However, to have attempted to trace all government organizations that are indirectly involved in the industry would itself probably have consumed most of our resources.

The range of employment in this area was from 82 person months to one person month (All quantities greater than .5 were rounded to one). In this category the seven largest agencies accounted for 54.31 percent of the geothermal related employment. A more thorough distribution is as follows.

Number of Agencies	Percent of manpower in state & local government
25	≥ 1
8	≥ .5 and < 1
0	≥ .4 and < .5
3	≥ .3 and < .4
1	≥ .2 and < .1
4	≥ .1 and < .2
0	< .1

Federal Government

Of the 34 federal government organizations responding, one accounted for 47.84 percent of the employment measured in our survey. There were seven with greater than one percent employment in this sector, and the cummulative total for these eight respondents was 90.96 percent. The following is a more complete distribution.

Number of Agencies	Percent of manpower in federal government
7	≥ 1
11	≥ .5 and < 1
0	≥ .4 and < .5
1	≥ .3 and < .4
4	≥ .2 and < .3
4	≥ .1 and < .2
7	< .1

Higher Education Institutions

A total of 69 colleges provided estimates for our survey. Over half (54.0 percent) of the total educational manpower was in the first seven respondents with the largest quantities. The final distribution is as follows.

Number of Colleges	Percent of manpower in educational institutions
24	≥ 1
16	≥ .5 and < 1
1	≥ .4 and < .5
8	≥ .3 and < .4
5	≥ .2 and < .3
8	≥ .1 and < .2
7	< .1

Analysis by Activities and Phases of Development

Our first initial mailing asked organizations to identify their manpower involvement by one (or more) of seven general activities or to list an activity if none of the others were appropriate. In addition, under the general activities the organizations were asked to list subcategories of specialization. This approach led to a large number of varied responses, which we then tried to condense into rational categories. The result is shown on the matrix on the next page. Although a smaller version of this matrix was used in the two subsequent initial mailings, the discussion and definitions given below pertain to the larger classification matrix.

Definition of Activities

The original attempt was to break down the distribution of person months only by activity. However, replies to the solicitation of activity by area of specialization greatly complicated this effort to the point that precise analysis by activity was impossible in many cases. Even in the revised list of activities there remain some conceptual problems of overlapping involvement (e.g., whether drilling should be a separate category). Still, the revised list of activities coupled with particular phases of involvement lends greater precision to the determination of where human resources are allocated. The specific activities used in classifying the initial responses are generally meant to be interpreted as the necessary stages of development at the resource site to bring about the utilization of the resource for electric generating and direct use applications which are socially, economically, and environmentally sound.

TYPE OF ORGANIZATION

Private firm or individual ___
State or local govt. ___
Federal govt. ___
Educational ___

File # ____

ACTIVITY / PHASE	Disassociated	Research & development of materials & equipment	Manufacture of materials & equipment	Sales/service of materials & equipment	Use of materials & equipment at temporary site-specific locations	Construction of permanent facilities	Operation/maintenance of permanent facilities	Planning, impact & feasibility studies	Consulting	Leasing & land administration	Finance	Legal	Education	Publishing	Government regulation	Supporting services
Disassociated																
Resource Exploration/assessment (exclusive of drilling)																
Reservoir design/development (exclusive of drilling)																
Well drilling & drilling services																
Plant design & construction																
Steam production/transmission																
Space heating																
Electrical energy production																
Agricultural applications																
Non-electrical industrial applications																
Environmental																

(1) Disassociated. This category was used in the reclassification of responses because many memorandum replies to the "other" category could not be associated with a particular activity. Therefore, a disassociated designation means that person months can be at least identified by either an activity or a phase.

(2) Resource exploration/assessment (exclusive of drilling) includes any site specific, regional, or national effort to inventory geothermal resources and to identify and define the characteristics and feasible development of individual reservoir systems. This activity includes remote sensing, surface, and subsurface techniques.

(3) Reservoir design/development (exclusive of drilling) includes the utilization of materials and methods which are necessary to transport or enhance the discovered resource for energy conversion or direct use. Examples are down-hole pumps, field stream control, design and analysis, scaling and corrosion control, and other activities relative to the physical and chemical characteristics of the reservoir.

(4) Well drilling and drilling services are composed of any drilling activity, preparation for drilling activity, and any direct support services necessary for the implementation or continuation of drilling. This category includes efforts aimed at assessing the resource (e.g., well logging and sampling) and at developing the resource in its various states.

(5) Plant design and construction (power plant only) applies to pilot plants and to larger commercial plants.

(6) Steam production and transmission is an activity that could perhaps be better characterized as a subcategory under reservoir design and development. But for purposes of consistency with earlier phases of

this study, it was necessary to maintain the general taxonomy. However, listing this activity does tend to make the associated manpower explicit. Ambiguity creeps in when some respondents may have considered steam production and transmission as an implied part of reservoir design and development and/or space heating.

(7) Space heating can be generally characterized by the development of heating systems for commercial, public, and private use.

(8) Electrical energy production applies basically to operation and maintenance manpower necessary for the production of electricity for commercial sale, for use in an adjunct commercial project, or for a project test facility which is anticipated to demonstrate commercial feasibility.

(9) Agricultural application contains any efforts directed at food growing (plant or animal). Greenhouses appear to be the dominant mode of this activity. However, it is important to note that at this time any assessment of direct use application is tenuous at best.

(10) Nonelectric industrial application is another direct use activity that takes into account the extraction of by-products from the resource (e.g., mineral recovery) and processing functions (e.g., food dehydration).

(11) Environmental activity incorporates any effort to study, monitor, establish standards, or regulate the quality of air, water, the surrounding habitat of fish and wildlife, and natural geologic features associated with existing and proposed geothermal developments.

Definition of Phases

The addition of the phase classifications produces both positive and negative benefits. Positive benefits include the following:

(1) A much clearer picture emerges of the extent of supporting services that may not be performed on the site of development. These services may be directly associated with particular development(s) (e.g., use of materials and equipment on temporary site specific locations), or they may be more geared to the industry in general (e.g., applied research);

(2) Quantities of manpower which do not require extended efforts of analysis or policy suggestions can be eliminated (e.g., consulting and publishing);

(3) The overall picture of manpower distribution in the geothermal industry is greatly enhanced because of the more precise taxonomy.

The negative factors are as follows:

(1) The use of the activity-phase matrix greatly complicates the analysis. It is more time consuming to classify responses and requires considerably more computer work;

(2) Some redundancy is created (e.g., construction of permanent facilities and plant design and construction);

(3) Some subjective judgment is required on the part of the investigator in order to fit some responses into the matrix.

This explanation of the activity-phase matrix approach is not intended for purposes of advocating a general method. The primary purpose is to demonstrate what had to be done after the fact (i.e., after the first initial mailing) in order to get a clearer picture of manpower distribution in the industry. Additionally, it should not be interpreted that each phase category is of equal precision. Particular attention should be paid to the definitions which demonstrate that some categories are much more broadly defined than others. This was necessary in order to avoid constructing a matrix of unmanageable proportions. The definitions used in classifying the phases of development are as follows:

(1) Disassociated. See previous definition.

(2) Research and development of materials, equipment, and methods refers to (a) basic research, especially in the geophysical and geochemical areas. This effort is primarily conducted in higher education research programs. It also includes (b) applied research which is geared toward solving particular technological problems, especially as spelled out by D.O.E. priorities in the industry, and (c) efforts aimed at predicting where the resource occurs and reservoir performance, i.e., computer and physical modeling.

(3) Manufacture of materials and equipment incorporates the physical production of a product and the design and technical support functions. Most respondents indicated activity in the area of different types of turbines, well head systems, and heat exchanger components. This seriously limits any inference from this category because of omitted elements on the manufacturing sector.

(4) Sales and service of materials and equipment is another area of limited inference because of the small number of respondents and their association with only a few of the activities.

(5) Use of materials and equipment in temporary site specific locations includes efforts to inventory resources, such as geological, geophysical, or geochemical surveys. Temporary test facilities and drilling are also contained in this phase.

(6) Construction of permanent facilities contains electric (power plants), direct use (agricultural and processing), and supporting (steam

gathering systems) activities.

(7) Operation and maintenance of permanent facilities applies to all categories in (b) above.

(8) Planning, impact, and feasibility studies. This phase embraces informational and program research and evaluation, policy research, user surveys, and analysis for scenario development.

(9) Consulting takes into account work done in both the public and private sectors. This category appears to be predominantly composed of single person operations with a few firms composed of several consultants. One marked problem in the classification used is the inability to identify the legal and finance phases with consulting work.

(10) Leasing and land administration. In the private sector one explicit characteristic was property acquisition for clients. In the public sector this is an area of major involvement for government agencies.

(11) Finance is a minor area that includes joint ventures, raising investment funds, and evaluating investment ventures.

(12) Legal is another minor category. Specific responses concerned environmental and tax codes, the development of laws concerning the resource, and leasing.

(13) Education. This phase contained only a small quantity of person months and is characterized by teaching and supportive research. Though it is not possible to strongly infer from the structure of this study, it appears that much of the research conducted in higher education is carried over into teaching and training research assistants.

(14) Publishing refers to books, maps, magazines, directories, and general information dissemination.

(15) Government regulation. This function includes a variety of reporting, review, evaluation, inspection, certification, coordinating, monitoring, and permitting activities.

(16) Supporting services. This category is a general catchall but specifically includes management and administrative support functions, data processing, clerical work, accounting, and contract work.

Distribution of Person Months by Activities and Phases

The matrices on pages II-26 through II-30 give a descriptive view of how manpower is allocated in the industry by the four organizational types combined and by each organizational type separately. These matrices show several cells which register no person months. An argument can perhaps be made that some person months allocated in other cells might be more accurately defined in some empty cells with given activities or phases. However, closer inspection reveals that these are mostly highly undeveloped or undefined activities (e.g., space heating and non-electrical industrial applications) or that they are only partially attached to the industry (e.g., legal and finance).

Rather than have several different discussions of the various activities and phases by organizational types, we will explore each activity in depth only one time and include appropriate comments pertaining to the type of organizations responding and to the particular phase of involvement. By concentrating on the more important aspects of manpower allocation in the industry we can hopefully avoid a deluge of comparisons that are only of minor importance.

Distribution of Person Months for All Organizations Combined

ACTIVITY \ PHASE	Disassociated	Research & development of materials & equipment	Manufacutre of materials & equipment	Sales/service of materials & equipment	Use of materials & equipment in temporary site-specific locations	Construction of permanent facilities	Operation/maintenance of permanent facilities	Planning, impact & feasibility studies	Consulting	Leasing & land administration	Finance	Legal	Education	Publishing	Government Regulation	Supporting Services	Horizontal Totals
Disassociated		675	5	195				532	192	1484	50	164	62	171	625	1206	5361
Resource Exploration/assessment (exclusive of drilling)	1794	4445	19	72	1852	143	296	316	378	896	5	2	26	12	45	6	10297
Reservoir design/development (exclusive of drilling)	280	1020	246	122	290	43	136	265	98	14			12		26		2552
Well drilling & drilling services	1247	834	483	507	2510	58	183	24	56	3	1				140	19	6065
Plant design & construction	261	278	74	5	133	1924	1253	211	49	2	3	2			60	40	4295
Steam production/transmission	1011	202	1	6		230	74		9	35	2				17		1587
Space heating	55	101				30	23	78	26						6		319
Electrical energy production	73	504	173	9	60	8	3	19	61	24	5				13		952
Agricultural applications	152	197				176		82							6		613
Non-electrical industrial applications		55						30									85
Environmental	132	446			8			749	161	184		3		30	83		1796
Vertical Totals	5005	8747	1001	721	5048	2612	1968	2315	1056	2609	64	171	100	213	1021	1271	

GRAND TOTAL 33,922

Distribution of Person Months for Private Firms and Individuals

ACTIVITY \ PHASE	Disassociated	Research & development of materials & equipment	Manufacutre of materials & equipment	Sales/service of materials & equipment	Use of materials & equipment in temporary site-specific locations	Construction of permanent facilities	Operation/maintenance of permanent facilities	Planning, impact & feasibility studies	Consulting	Leasing & land administration	Finance	Legal	Education	Publishing	Government Regulation	Supporting Services	Horizontal Totals
Disassociated		396			195			488	156	334	32	74	31	161		966	2833
Resource Exploration/assessment (exclusive of drilling)	1602	1027	19	72	1733	143	266	77	354	212	5	2		12		6	5530
Reservoir design/development (exclusive of drilling)	258	580	246	122	275	43	106	2	98	12							1742
Well drilling & drilling services	1219	757	483	507	2444	58	183	9	56	1	1				25	19	5762
Plant design & construction	251	180	74	5	93	1838	1253	177	9		3	2				40	3925
Steam production/transmission	999	202	1	6		230	74	7	35	2					10		1566
Space heating	51	92				30	23	59	26								281
Electrical energy production	30	258	173	9	60	8	3	19	61	24	5				1		651
Agricultural applications	54	164				176		39									433
Non-electrical industrial applications		55						30									85
Environmental	14	259			6			244	72	137		3			6		741
Vertical Totals	4478	3970	996	721	4806	2526	1908	1151	867	722	46	71	31	173	42	1031	

TOTAL 23,549

Distribution of Person Months for State and Local Government

ACTIVITY \ PHASE	Disassociated	Research & development of materials & equipment	Manufacutre of materials & equipment	Sales/service of materials & equipment	Use of materials & equipment in temporary site-specific locations	Construction of permanent facilities	Operation/maintenance of permanent facilities	Planning, impact & feasibility studies	Consulting	Leasing & land administration	Finance	Legal	Education	Publishing	Government Regulation	Supporting Services	Horizontal Totals
Disassociated								14		72				3	139		228
Resource Exploration/assessment (exclusive of drilling)	33	56			45			11		7					6		158
Reservoir design/development (exclusive of drilling)	6							13		2					10		31
Well drilling & drilling services		1						3		2					99		105
Plant design & construction	2							34		2					60		98
Steam production/transmission								2							6		8
Space heating								14							6		20
Electrical energy production															12		12
Agricultural applications															6		6
Non-electrical industrial applications																	0
Environmental	2							14						30	65		111
Vertical Totals	43	57			45			105		85				33	409		

TOTAL 777

Distribution of Person Months for the Federal Government

ACTIVITY \ PHASE	Disassociated	Research & development of materials & equipment	Manufacutre of materials & equipment	Sales/service of materials & equipment	Use of materials & equipment in temporary site-specific locations	Construction of permanent facilities	Operation/maintenance of permanent facilities	Planning, impact & feasibility studies	Consulting	Leasing & land administration	Finance	Legal	Education	Publishing	Government Regulation	Supporting Services	Horizontal Totals
Disassociated			5							1066		12			486	12	1581
Resource Exploration/assessment (exclusive of drilling)	16	2334					30	34	3	677					39		3133
Reservoir design/development (exclusive of drilling)	1	5					30	22							16		74
Well drilling & drilling services	28														16		44
Plant design & construction		4															4
Steam production/transmission	12														1		13
Space heating																	0
Electrical energy production																	0
Agricultural applications		6															6
Non-electrical industrial applications																	0
Environmental	118	141						440	83	47					12		841
Vertical Totals	175	2490	5				60	496	86	1790		12			570	12	

TOTAL 5696

Distribution of Person Months for Educational Institutions

ACTIVITY \ PHASE	Disassociated	Research & development of materials & equipment	Manufacutre of materials & equipment	Sales/service of materials & equipment	Use of materials & equipment in temporary site-specific locations	Construction of permanent facilities	Operation/maintenance of permanent facilities	Planning, impact & feasibility studies	Consulting	Leasing & land administration	Finance	Legal	Education	Publishing	Government Regulation	Supporting Services	Horizontal Totals
Disassociated		279						30	36	12	18	78	31	7		228	719
Resource Exploration/assessment (exclusive of drilling)	143	1018			74			194	21				26				1476
Reservoir design/development (exclusive of drilling)	15	435			15			228					12				705
Well drilling & drilling services		76			66			12									154
Plant design & construction	8	94			40	86			40								268
Steam production/transmission																	0
Space heating	4	9						5									18
Electrical energy production	43	246															289
Agricultural applications	98	27						43									168
Non-electrical industrial applications																	0
Environmental		44			2			51	6								103
Vertical Totals	311	2228			197	86		563	103	12	18	78	69	7		228	

TOTAL 3900

Resource Exploration and Assessment (excluding drilling)

Nearly one third (30.4 percent) of all manpower measured in our survey was engaged in this activity, and this was (in 1977) the highest allocation of manpower in any activity. This reflects both the labor intensity of this activity and the fact that it is a necessary pre-requisite for further industry development. That is, it reflects the particular stage of growth in which the industry is most importantly involved. It should also be noted that this is the only activity which correlated with every phase of development.

The largest allocation (4445 person months) in terms of the phase of development in this activity was in "research and development of materials and equipment." It is interesting to note that the largest portion of this allocation was federal government employment (2334 person months), and it was more than double the manpower allocation of any other cell in the matrix pertaining to this activity from other organizational types.

The temporary on-site use of materials and equipment accounted for only 1852 person months or 18.0 percent of the entire resource exploration and assessment activity. Even combined with the phases of "construction of permanent facilities" and "operation and maintenance of permanent facilities", the share is only raised to 22.2 percent of all resource exploration and assessment activities. This emphasizes the large amount of direct and indirect support (in terms of manpower) needed to maintain on-site activities.

Reservoir Design and Development (excluding drilling)

This activity has 7.52 percent (2552 person months) of the total estimated manpower. Nearly half, 1020 person months, is allocated to research and development of materials and equipment and most of this R & D is being carried on by the private sector (580 person months). Again, the direct on-site activities account for only 18.4 percent of the employment in this activity.

Well Drilling and Drilling Services

This was the second largest activity and represented 18 percent of the total estimated manpower. The high labor intensity of this activity is also reflected by the ratio of on-site efforts to total estimated manpwer in the activity, 45.4 percent. The R & D efforts are also substantial, 13.8 percent.

Plant Design and Construction

This activity accounts for 12.7 percent of the total employment. It is similar to well drilling in that the ratio of on-site to total employment in the activity is quite high (77.1 percent) relative to other activities.

Steam Production and Transmission

The bulk of this activity appears to be specifically designated to the construction of permanent facilities (i.e., the reservoir feed system).

Also, this activity is almost exclusively (98.7 percent) concentrated in the private sector.

Space Heating

Space heating was the second smallest activity in terms of manpower with only 319 person months given. This activity is also highly concentrated in the private sector with 281 person months (or 88.1 percent).

Electrical Energy Production

This is one activity in which the results were clearly unsatisfactory in at least one phase, "operation and maintenance of permanent facilities", which registered only three person months. Fortunately, we were able to obtain adequate information for other purposes in this area with the personal interview phase. Our results do show that there is a high concentration of manpower in research and development (504 of a total 952 person months in this activity). This effort is relatively evenly divided between the private sector (318 person months) and education institutions (246 person months).

Agricultural Applications

This is another activity which is dominated by the private sector with 433 of a total of 613 person months. The major phases of manpower allocation are in research and development (197 person months) and construction of permanent facilities (176 person months).

Nonelectrical Industrial Applications

With only 85 person months this activity has the smallest amount of manpower. This allocation is divided between R & D (55 person months) and "planning, impact and feasibility studies" (30 person months).

Environmental

As indicated in the personal interview phase and technology assessment phase of our study, it is our view that this will be a growing area of employment. According to our estimates it accounted for 5.3 percent (1796 person months) of the total employment in 1977. The basic phases of involvement were research and development, planning, impact and feasibility studies, consulting, leasing and land administration.

Conclusions

The discussion until now has been oriented toward the distribution of person months by activities and has demonstrated that the four major activities -- resource exploration and assessment, reservoir design and development, well drilling and drilling services, and plant design and construction -- account for 23,209 person months (or 68.4 percent) of all manpower estimated in our survey. However, we cannot conclude that this amount of manpower is used directly at the development site. To get a better estimate of on-site activities one must examine the totals under the different categories under the phase heading.

We believe three phases of development -- use of materials and equipment in termporary site-specific locations, construction of permanent facilities, and operation and maintenance of permanent facilities -- take into account most on-site activities. In fact the total under these categories for all organizations combined is 9628 person months (or 28.4 percent). This is considerably less than the total person months estimated in our survey, and it takes much of the guesswork out of trying to determine what proportion of the total employment would be directly related to site-specific development if one were only looking at total employment by activity. This sets the stage for a digression into the development of an employment multiplier for the industry which can be used in our forecasting model.

The Development of an Employment Multiplier

With the possible exception of resource exploration and assessment, our forecasting model (Part IV of this study) was geared exclusively toward employment that we expected to be utilized at the development site. Therefore, for reasons of consistency this is the portion of the matrix which will be used as a base in developing a multiplier. We will develop a multiplier only for the private sector but for reasons of completeness will then point out what might be the expected employment in the other three organizational types.[1]

As previously mentioned, one of the weak links in this approach is in the activity of electrical energy production. We do not feel that the

[1]Another approach could have been to develop the multiplier for all organizations taken together, but we believe this would have introduced even more questionable assumptions about fixing the ratio of employment in other organizational types to the private sector.

mail survey generated a manpower profile for this activity that reflects actual employment. However, this shortcoming is at least partially compensated by our confidence in estimates within other activities.

Since our forecasting model is based only on commercial electrical energy production, we must subtract space heating, agricultural application, and nonelectrical industrial applications from the total of on-site activities (as denoted by the temporary activities, construction activities, and operation and maintenance activities under the phase heading), or 9240 person months — 229 person months = 9011 person months. It should be noted that this is only what we can measurably delete. It seems likely that some portion of the other activities (e.g., resource exploration, reservoir design, and well drilling) would be directed toward direct use, but these cannot be measured. However, considering the small portion of the activities that were deleted, this should not be a serious problem.

Taking the 9011 person months derived above we now form a ratio with all other person months within the matrix for the private sector which cannot be directly related to site-specific development in the numerator (= 14,538 person months) and 8951 person months in the denominator. This gives a multiplier of 14,538 ÷ 9011 = 1.61 for the private sector. That is, for every person month of employment generated at the site 1.61 person months of employment will be generated elsewhere in the industry. Note that this is not a multiplier of employment in the secondary sector, but it is for employment directly related to the geothermal industry (e.g., R & D, consulting, legal services, etc.).

Since the other organizational types in the industry -- state and local government, federal government, and educational institutions --

form 30.6 percent of the total estimated manpower, one might use this as a guideline for the additional employment which will be generated. However, it is not recommended that it be used as a rigid multiplier.

Final Mail Survey

All organizations which responded to the first phase of our mail survey were candidates to be surveyed in the final mailing unless they explicitly replied that further participation was not desired or unless they were selected for the personal interview phase. This left a total of 367 organizations for the final survey, and these were distributed as follows:

Private firm or individual	251
State or local government	33
Federal government	23
Education	60
Total	367

The questionnaire used in the final mail survey (see Appendix II-A) was designed to gain more specific knowledge about the structure of the industry (Part C: Primary Activity), fluctuation in employment and geothermal employment as a part of total employment (Part D: Employment Summary), occupational structure by activities (Part E: Occupational Employment in Geothermal Activities), attachment to on-site activities (Part F: Geographic Sites), and the proportion of budget and workforce devoted to research and development (Part G: Research and Development).[1]

[1] Parts A and B were explanatory and asked for corrected mailing address.

The results from the survey as a whole were mixed, and each will be discussed in turn according to the questionnaire titles cited above.

Of these 367 a total of 232 were accounted for after an initial and a follow-up mailing. The following describes how the number of useful responses was derived.

Total mailed	367
Nonrespondents	-135
Nondeliverables	- 4
No longer in the industry	- 6
Decided not to participate	- 4
No data supplied	- 4
Respondents which provided data on at least one part of the questionnaire.	214

Given below is the response rate by organizational type based on the 214 respondents. Also listed are the means and medians of employment in person months by organizational type. The combined response rate was 58.3 percent (214 ÷ 367), the combined mean was 54.5, and the combined median was 13.

Organization Type	Response Rate	Mean	Median
Private firm or individual	48.6%	62.3	12
State or local government	70.0%	26.7	16
Federal government	78.3%	59.6	30
Education	61.7%	49.1	18

Primary Activity

Under this category we attempted to gain a more useful profile by seeking the Standard Industrial Classification (S.I.C.) codes from the respondents. The results echoed those of the personal interview phase in that only a very few organizations replied to this question. The number of organizations that did respond with codes was 14 which was only 6.5 percent of the total. The codes are listed below with each organization's identification number.

Identification No.	S.I.C. code(s)
FW2	9999
FW31	1629
FW11	44
FJ5	1389
FI5	9193
FI3	9511
FH40	3600
FH21	8601
FE29	7389
FE19	3563, 3511
FD1	8980
DC77	8999
FW2	9999
FW31	1629
FW11	44
FJ5	1389
FI5	9193
FI3	9511
FH40	3600
FH21	8601
FE29	7389
FE19	3563, 3511
FD1	8980
FC77	8999
FC50	4931
FC21	9631

Employment Summary

This section of the questionnaire had two purposes. The first was to gain some insight into the relative importance (in terms of manpower) of geothermal activities in relation to other activities in which the organizations are involved. The second purpose was to obtain data for 1977 and 1978 to see if there was an obvious growth trend. Table II-6 on the next page summarizes the results.

A central problem in forming geothermal to total employment ratios is the level of aggregation. This is especially true for the different levels of government and for educational institutions. Therefore, as a first point it may be argued that the geothermal to total employment ratios demonstrate the relative unimportance of the industry in relation to the total employment of the organizations involved. Given the low ratios (for 1977 and 1978 respectively) -- educational institutions (1.24% and 1.43%), federal government (.6% and .54%), state and local government (4.47% and 5.12%), and the private sector (.23% and .29%) -- this appears to be true for any particular organizational group, but it is important to keep in mind that some organizations (especially in the private sector) may be totally dependent on the geothermal industry.

One notable feature of the ratios is that they demonstrate a slight increase between 1977 and 1978, with the exception of the federal government. However, if one looks at the increase for all organizational types added together, it only amounts to .05 percent.

Finally, the ratio for the private firms surveyed by personal interview was 1.42 percent (923 ÷ 65,123). This is considerably higher than the mail survey (.23 percent), but it is also not surprising since we purposefully tried to include the larger firms in the personal interviews.

TABLE II-6

Ratios of Geothermal to Total Employment by Organizational Type

	1977	1978
Private Firm or Individual	$\frac{779}{326,811}$ = .23%	$\frac{1008}{347,541}$ = .29%
State & Local Government	$\frac{127}{2838}$ = 4.47%	$\frac{155}{3025}$ = 5.12%
Federal Government	$\frac{285}{47,854}$ = .60%	$\frac{258}{47,639}$ = .54%
Educational Institution	$\frac{185}{14,922}$ = 1.24%	$\frac{227}{15,841}$ = 1.43%

Occupational Employment in Geothermal Activities

This section of the questionnaire was designed to obtain a very general occupational profile by the different activities in the industry. The following discussion is based on the data presented in the matrices on the following pages.

One might expect the occupational group of scientists and engineers to represent a large proportion of the total quantity of manpower in the industry. However, based on the 200 respondents to this part of our survey, the scientists and engineers category not only assumes a large proportion but also clearly dominates the manpower structure of the industry. With all organization types taken together scientists and engineers account for 7,341 (or 59.3%) of the total 12,375 measured person months. This preponderance exists not only for all organizations taken together but for each organizational type examined separately.

The above description holds true not only for each organizational type but also for each activity within any given organizational type with only two exceptions. In the activity of well drilling and drilling services the "all others" category is the largest for all organizational types added together and for the separate category pertaining to the private sector. The other exception is in the private sector activity of electrical energy production and transmission in which the dominant occupational group is technicians.

Geographic Sites

We attempted to have the organizations respond by their involvement at particular Known Geothermal Resource Areas (KGRA's). The initial

Total Person Months for All Organizational Types

	Scientists & Engineers	Technicians	Skilled Workers	All Others	Horizontal Totals
Resource Exploration & Assessment (exclusive of drilling)	2436	568	85	359	3448
Reservoir Design & Development (exclusive of drilling)	460	196	2	70	728
Well Drilling & Drilling Services	522	401	508	597	2028
Plant Design and Construction	554	139	98	59	850
Steam Production and Transmission	267	71	20	72	430
Electrical Energy Production & Transmission	197	39	0	14	250
Space Heating	84	4	1	35	121
Agriculture Operations	120	33	0	8	161
Non-electric Industrial Applications	410	24	14	36	484
Environmental	988	260	6	134	1388
Other	1306	441	61	679	2487
Vertical Totals	7341	2176	795	2063	Matrix Total 12,375

Total Person Months for Private Sector

	Scientists & Engineers	Technicians	Skilled Workers	All Others	Horizontal Totals
Resource Exploration & Assessment (exclusive of drilling)	1559	399	52	185	2195
Reservoir Design & Development (exclusive of drilling)	227	114	0	67	408
Well Drilling & Drilling Services	364	331	430	475	1600
Plant Design and Construction	374	63	14	53	504
Steam Production and Transmission	71	22	0	6	99
Electrical Energy Production & Transmission	24	30	0	10	64
Space Heating	28	2	0	35	65
Agriculture Operations	32	14	0	8	54
Non-electric Industrial Applications	47	2	0	2	51
Environmental	448	74	0	2	524
Other	537	171	39	54	801
Vertical Totals	3711	1222	535	897	Matrix Total 6365

Total Person Months for State & Local Government

	Scientists & Engineers	Technicians	Skilled Workers	All Others	Horizontal Totals
Resource Exploration & Assessment (exclusive of drilling)	172	21	0	6	199
Reservoir Design & Development (exclusive of drilling)	10	0	1	0	11
Well Drilling & Drilling Services	27	0	0	12	39
Plant Design and Construction	5	0	0	0	5
Steam Production and Transmission	4	3	0	0	7
Electrical Energy Production & Transmission	0	0	0	0	0
Space Heating	12	0	1	0	13
Agriculture Operations	2	0	0	0	0
Non-electric Industrial Applications	61	0	14	20	95
Environmental	60	6	0	12	78
Other	56	0	1	106	163
Vertical Totals	409	30	17	156	Matrix Total 612

Total Person Months for Federal Government

	Scientists & Engineers	Technicians	Skilled Workers	All Others	Horizontal Totals
Resource Exploration & Assessment (exclusive of drilling)	96	26	1	18	141
Reservoir Design & Development (exclusive of drilling)	45	4	1	3	53
Well Drilling & Drilling Services	113	48	2	0	163
Plant Design and Construction	2	0	0	0	2
Steam Production and Transmission	0	0	0	0	0
Electrical Energy Production & Transmission	0	9	0	0	9
Space Heating	0	0	0	0	0
Agriculture Operations	0	0	0	0	0
Non-electric Industrial Applications	0	0	0	0	0
Environmental	105	78	0	16	199
Other	53	6	4	81	144
Vertical Totals	414	171	8	118	Matrix Total 711

Total Person Months for Educational Institutions

	Scientists & Engineers	Technicians	Skilled Workers	All Others	Horizontal Totals
Resource Exploration & Assessment (exclusive of drilling)	609	122	32	150	913
Reservoir Design & Development (exclusive of drilling)	178	78	0	0	256
Well Drilling & Drilling Services	4	0	0	0	4
Plant Design and Construction	131	0	0	0	131
Steam Production and Transmission	0	0	0	0	0
Electrical Energy Production & Transmission	1	0	0	0	1
Space Heating	9	2	0	0	11
Agriculture Operations	10	1	0	0	11
Non-electric Industrial Applications	8	0	0	0	8
Environmental	47	0	0	0	47
Other	310	22	15	16	363
Vertical Totals	1307	225	47	166	Matrix Total 1745

intent was to try to assess the magnitude of labor impact on a more local level. However, this was not a highly productive approach since many firms did not know the formal KGRA designations or replied with some other geographic designation. Also, involvement in specific areas is only a short-term phenomenon for most organizations, and it is not possible to determine the proportion of their total geothermal employment which may be involved at any particular area at a given time.

It is noteworthy that most organizations did view themselves as involved with at least one KGRA. This indicates the strength of attachment to site-specific developments of our final survey group. Table II-7 gives a breakdown of the respondents to this question.

Research and Development

Table II-8 shows a partial breakdown by organization type of the responses to the question, "What percent of your organization's total geothermal budget in 1977 was in research and development?" Note that many organizations left part or all of this section blank. These are deleted from the count, and only the organizations which explicitly stated zero are counted in this category.

One particular observation from Table II-8 is that many firms (34) in the private sector are exclusively involved in research and development. In other words, as a proportion of total respondents (111) to this category, 30.6 percent of the firms have their budget 100 percent allocated to research and development activities. This is also quite comparable to the results from our personal interview survey in which five out of the twenty firms responding to this question were 100 percent

TABLE II-7

	Indicated no involvement at a KGRA	Not Responding to the Question	Indicated involvement with at least one KGRA	Horizontal Totals
Private firm or individual	38	12	83	133
State or local government	3	2	18	23
Federal government	2	0	16	18
Educational	11	3	26	40
			Total for all organizations	214

TABLE II-8

R & D Budget as a Percent of Total Budget

Private Firms or Individuals		State & Local Governments		Federal Government		Educational Institutions	
% of budget	# responding	% of budget	# responding	% of budget	# responding	% of budget	# responding
100	34	100	10	100	5	100	16
50 - 99	15	50 - 99	1	50 - 99	0	50 - 99	3
1 - 49	17	1 - 49	2	1 - 49	0	1 - 49	4
0	45	0	9	0	12	0	3

TABLE II-9

Percent of Geothermal Workforce Engaged in R & D

Private Firms or Individuals		State & Local Governments		Federal Government		Educational Institutions	
% in R & D	# responding	% in R & D	# responding	% in R & D	# responding	% in R & D	# responding
100	32	100	12	100	5	100	20
50 - 99	17	50 - 99	1	50 - 99	0	50 - 99	2
1 - 49	21	1 - 49	0	1 - 49	0	1 - 49	5
0	47	0	8	0	12	0	6

involved in research and development. Based on our discussion of occupational employment by geothermal activity, it appears that R & D underpins much of the relatively high proportion of employment of scientists and engineers in the industry.

Table II-9 is based on responses to the question, "What percent of your organization's total geothermal workforce is engaged in research and development?" The table indicates that the R & D budget allocation is highly correlated with the relative proportion of employment in this activity in the private sector. That is, 52.1 percent of private firms responding to this category indicated that some proportion of their manpower were involved in research and development efforts. This is slightly higher than the 49.6 percent which gave the same indication for the first question on budget allocation.

Conclusion

Though the matrices on which much of the discussion in this part of the study is based contain some abiguities, they have proven to be a useful tool in analyzing where manpower is allocated in the geothermal industry. For example, it is obvious that research and development is the dominant phase of activity in the industry, and the dominant activity is resource exploration and assessment. Both of these reflect the infant nature of the geothermal industry.

Another finding is that scientists and engineers compose more than half of the estimated manpower requirements in the industry. Finally, it appears that manpower is highly concentrated in only a few firms which form the stable core of employment for the industry with which a large number of smaller peripheral (marginally attached) firms are associated.

II

APPENDIX II-A

II 54

Cover Letter and Questionnaires Used in
the Three Initial Mail Surveys

THE UNIVERSITY OF UTAH

HUMAN RESOURCES INSTITUTE
ROOM 412
COLLEGE OF BUSINESS BUILDING
SALT LAKE CITY, UTAH 84112
(801) 581-6127

Dear Sirs:

Possibilities of rapid expansion in the development of geothermal energy resources have focused attention on the potential manpower requirements of such development.

The Department of Energy has asked us to conduct a survey of employment by occupation in geothermal related activities during 1977 as a base from which to project manpower requirements to 1985. The objective is to provide early warning to government and industry if any potential manpower problems are implied.

To assist in selecting a sample for the survey which is to occur in November 1978, we ask your organization to complete and return the enclosed memorandum by November 1,1978. If your organization is chosen to participate in that sample, you will be supplied with its results, as well as the projections to follow.

We greatly appreciate your cooperation in this matter.

Sincerely,

Garth Mangum

Garth L. Mangum
Principal Investigator

GLM:gl

Encls.

DATE: February ____, 1978

MEMORANDUM

II 5

TO: GEOTHERMAL MANPOWER PROJECT
Human Resources Institute
412 Business Office Building
University of Utah
Salt Lake City, Utah 84112

FROM:

RE: Mail sample survey of employment by occupation in the geothermal industry

☐ Our organization was not engaged in geothermal related activities during 1977.

1) Total employment in our various geothermal operations were as follows during 1977 (counting persons on own payroll--including supervisory, clerical, data processing, and other supporting personnel--working at the above address or at branch/field offices):

	We Specialize In (specify research area, type of consulting work, drilling service performed, type of construction company, etc.)	Person Months*
Resource exploration and assessment	____	____
Reservoir design and development	____	____
Well drilling and drilling services	____	____
Plant design and construction	____	____
Steam production and transmission	____	____
Space heating	____	____
Agricultural applications	____	____
Other (specify) ____	____	____
____	____	____
____	____	____

The above information will be used to select a stratified random sample for a mail survey to be conducted in April 1978. We can assure you the questionnaire being developed for the survey does not solicit financial or technical information.

2) If our organization is selected to participate in the April survey, the questionnaire should be mailed to:

____ (Division/Department) ____ (Address--if different from above)

____ (Contact Person) ____ (Area code - phone # - X)

3) Our organization contracted geothermal work during 1977 to (please list contractors if the work performed for your organization totalled $25,000 or more):

Contractor name ____ Address ____

____ ____

Contractor name ____ Address ____

____ ____

(Please continue on back of page if more space is needed)

____
(Signature and Title of Respondent)

*To avoid possible misintrepretation, one person working in geothermal related activities for twelve months should be counted as 12 person months; two persons for three months should be counted as 6 person months, etc.

II

DATE: October 13, 1978

MEMORANDUM

TO: GEOTHERMAL MANPOWER PROJECT
Human Resources Institute
412 Business Office Building
University of Utah
Salt Lake City, Utah 84112

FROM:

RE: Mail Sample Survey of Employment by Occupation in the Geothermal Industry

☐ Our organization was not engaged in geothermal related activities during 1977.

(1) Total employment in our various geothermal operations were as follows during 1977 (counting persons on own payroll — including supervisory, clerical, data processing, and other supporting personnel — working at the above address or at branch/field offices.

Please enter into the appropriate block (denoting the industry activity most closely associated with the particular nature of involvement) the number of person months.*

ACTIVITY \ NATURE OF INVOLVEMENT	Research & development	Manufacturing of materials/ equipment	Sales & service of materials/ equipment	Construction	Operations & maintenance of on-site projects & permanent facilities	Impact & feasibility studies	Consulting	Leasing	Other (specify)				
Resource exploration & assessment (exclusive of drilling)													
Reservoir design & development (exclusive of drilling)													
Well drilling & drilling services													
Plant design & construction													
Steam production & transmission													
Space heating													
Electric power generation & transmission													
Agricultural applications													
Environmental													
Other (specify)													

The above information will be used for a mail survey to be conducted in November 1978. We can assure you the questionnaire being developed for the survey does not solicit financial or technical information.

(2) If your organization does not wish to participate in the September survey, please check.________

(3) If your organization is selected to participate in the September survey, the questionnaire should be mailed to:

________________________ (Division/Department)

________________________ (Address—if different from above)

________________________ (Contact Person)

________________________ (Area Code - Phone # - X)

(4) Our organization contracted geothermal work during 1977 to (please list contractors if the work performed for your organization totalled $25,000 or more):

Contractor name ________________ Address ________________

Contractor name ________________ Address ________________

________________________ (Signature and Title of Respondent)

*To avoid possible misintrepretation, one person working in geothermal related activities for twelve months should be counted as 12 person months; two persons for three months should be counted as 6 person months, etc.

Cover Letter, Follow-up Letter, and

Questionnaire Used in Final Mail Survey

THE UNIVERSITY OF UTAH

HUMAN RESOURCES INSTITUTE
ROOM 412
COLLEGE OF BUSINESS BUILDING
SALT LAKE CITY, UTAH 84112
(801) 581-6127

March 30, 1979

Dear Sir:

Thank you for responding to our initial inquiry concerning manpower in the geothermal industry, and for your willingness to participate in a follow-up survey. As you will recall, the purpose of our study is to estimate the present and future manpower requirements in the geothermal industry for the Dept. of Energy.

Because of the many unfortunate delays in the progress of this project, we have included a copy of your initial response so you may more easily recall your involvement with our investigation. Also, the final questionnaire is enclosed. It is designed to obtain a general occupational breakdown and other relative information necessary to maximize the usefulness of the data we already have.

We have tried to include all the general activities that have come to our attention from the initial questionnaire responses. Please note that since you have already given this information, it is not necessary for you to list your specific type of activities (e.g., R & D, consulting, regulation, sales & service, manufacturing, etc.) unless they cannot in your opinion be subsumed under the general categories provided. Definitions of activities and occupations are given on pages 3 and 4. However, we realize that it is impossible to include all potential activities and specialities in a short list and therefore have included "other" at the end of the activities list for your use if necessary. Again, I would like to stress that any information you supply will be held in strictest confidence. Finally, we would be very interested in any comments you may have concerning manpower needs of the geothermal industry.

A summary report of our study will be provided at your request. You need only indicate so on the first page of the questionnaire. Your patience and efforts are very much appreciated, and we wish you continued success in the geothermal industry.

Sincerely,

Richard Hannah

Richard Hannah
Research Economist

RH:gl

Encls.

THE UNIVERSITY OF UTAH

HUMAN RESOURCES INSTITUTE
ROOM 412
COLLEGE OF BUSINESS BUILDING
SALT LAKE CITY, UTAH 84112
(801) 581-6127

II 60

March 30, 1979

Dear Sir:

This is a follow-up letter to our final questionnaire relating to employment in the geothermal industry which you received last January. We are nearing the completion of our survey and would like to offer this letter as a reminder that we still need your help.

In case you have misplaced the first copy of the questionnaire, we have enclosed another copy for your convenience. It will take only a few minutes of your time, especially since each question may not be applicable to your organization. As always, we are open to your comments concerning manpower requirements in the geothermal industry.

Thank you for your time and patience.

Sincerely,

Richard Hannah

Richard Hannah
Research Economist

RH:gl

Encls.

Approval Expires June 30, 1979

II (l

UNIVERSITY OF UTAH
SALT LAKE CITY, UTAH 84112

A SURVEY OF GEOTHERMAL RELATED EMPLOYMENT

Sponsor: U.S. Department of Energy
Division of Manpower Assessment
and Geothermal Energy

Participation in this survey is voluntary. The information your organization provides will be kept strictly confidential. Data will be summarized, analyzed, and published in aggregated form to assure confidentiality of individual responses. Your cooperation is needed to make the results of this survey comprehensive, accurate, and timely.

A metered return envelope is enclosed for your convenience. Contact Richard Hannah if you have any questions on how to complete this questionnaire: (801) 581-8760 or 6127.

Reply Date: Please complete and return this questionnaire by April 30, 1979 to avoid further correspondence.

Survey Results: Would you like a copy of the summary report of this study?

Yes No (please circle)

A. ORGANIZATION (please correct if necessary)

Person completing this questionnaire:

Name ____________________

Title ____________________

Phone ____________________

B. SCOPE OF SURVEY

For the purposes of this survey, an organization is considered to be in geothermal or geothermal related energy work if it is engaged in any of the activities listed in the definitions on page 3.

C. PRIMARY ACTIVITY

What is the Standard Industrial Classification (SIC) code of your organization, if known? ____________________
(The SIC code is the code number which best describes the most important product or service provided by your organization).

D. EMPLOYMENT SUMMARY

1. What was the total number of employees in your organization in the payroll periods which included:

   (a) September 12, 1977 ____________________, and

   (b) September 12, 1978 ____________________? Include all employees whether or not engaged in geothermal related activities.

2. Of the total number of employees reported above, how many were working in geothermal related activities?

   (a) September 12, 1977 ____________________

   (b) September 12, 1978 ____________________

II-62

E. OCCUPATIONAL EMPLOYMENT IN GEOTHERMAL ACTIVITIES

In the table below are listed different types of geothermal activities, some with which your firm identified itself. For each applicable activity please enter under each occupational category the best estimate available of total person months of geothermal employment during 1977 (total number of different persons engaged in geothermal activities during the year times the number of months each worked in these activities -- e.g., one person working in a geothermal activity for twelve months should be counted as twelve person months; two persons for three months should be counted as six person months, etc.). See definitions of occupations and activities on pages 3 and 4.

Types of Activity	Scientists & Engineers	Technicians	Skilled Workers	All Others
Resource Exploration & Assessment (exclusive of drilling)				
Reservoir Design & Development (exclusive of drilling)				
Well Drilling & Drilling Services				
Plant Design and Construction				
Steam Production & Transmission				
Electrical Energy Production & Transmission				
Space Heating				
Agriculture Operations				
Non-electric Industrial Applications				
Environmental				
Other				
Other				

F. GEOGRAPHIC SITES

In which Known Geothermal Resources Areas (KGRA's) or other geothermal sites was your organization involved during 1977? See definition of KGRA's on page 4.

KGRA ____________________ KGRA ____________________

KGRA ____________________ Other ____________________

Not involved with a KGRA __________ (please check)

G. RESEARCH AND DEVELOPMENT (See definition on page 4)

1. What percent of your organization's total geothermal budget in 1977 was in research and development? ________ percent
2. What percent of your organization's total geothermal workforce is primarily engaged in research and development? ________ percent

THANK YOU FOR YOUR COOPERATION

DEFINITIONS

TYPE OF ACTIVITY

Resource Exploration and Assessment - (exclusive of drilling) includes any site specific, regional, or national effort to inventory geothermal resources and to identify and define the characteristics and feasible development of individual reservoir systems. This activity includes remote sensing, surface, and subsurface techniques.

Reservoir Design and Development - (exclusive of drilling) includes the utilization of materials and methods which are necessary to enhance the discovered resource for energy conversion or direct use. Examples are down hole pumps, field stream control, design and analysis, scaling and corrosion control, and other activities relative to the physical and chemical characteristics of the reservoir. This activity excludes transmitting the steam which is treated below.

Well Drilling and Drilling Services - are composed of any drilling activity and any direct support services necessary for the implementation or continuation of drilling. This category includes efforts aimed at assessing the resource (e.g., well logging and sampling) and at developing the resource in its various states.

Plant Design and Construction - applies to electrical generating plants only but includes both pilot plants and larger commercial plants.

Steam Production and Transmission - encompasses the process involved in transmitting the resource from the wellhead to the site of use, either for energy conversion or direct use (excluding space heating).

Electrical Energy Production and Transmission - applies basically to operation and maintenance manpower necessary for the production of electricity for commercial sale, for use in an adjunct commercial project, or for a project test facility which is anticipated to demonstrate commercial feasibility.

Space Heating - includes any direct use application for heating residential, commercial, or governmental establishments.

Agricultural Operations - include any effort directed at using the geothermal resource for food growing (plant or animal) in greenhouses or any other establishment designed for this purpose.

Nonelectric Industrial Application - another direct use activity that takes into account the extraction of by-products from the resource (e.g., mineral recovery) and processing functions (e.g., food dehydration).

Environmental Activity - incorporates any effort to study, monitor, establish standards, or regulate the quality of air, water, the surrounding habitat of fish and wildlife, and natural geologic features associated with existing and proposed geothermal developments.

OCCUPATIONS

Scientists - persons who are actually engaged in scientific work at a level which requires a knowledge or the equivalent to that acquired through completion of a four-year college course with a major in one of the science fields, regardless of whether they hold a degree. Includes persons employed in such occupations as geologist, physicist, and mathematician, etc.

Engineers - persons actually engaged in civil, electrical, mechanical, metallurgical, and other types of engineering work at a level which requires knowledge of engineering equivalent at least to that acquired through completion of a four-year college course, regardless of whether they hold a degree.

Technicians - persons who work in direct support of engineers and scientists, utilizing theoretical knowledge of fundamental scientific, engineering, mathematical, or draft design principles. Work usually requires some post-high school training or its equivalent, but less than a bachelor's degree.

Skilled Workers - persons in production, maintenance, construction, repair, powerplant, and material handling occupations that predominantly require a thorough and comprehensive knowledge of processes involved in the work, the exercise of considerable independent judgment, and usually a high degree of manual dexterity. Includes persons employed in such occupations as electricians, boilermakers, machinists, tool and die makers, etc.

All Other Workers - includes but not limited to clerical workers, service and sales workers, operatives, and laborers. Non-scientific, non-engineering professional workers such as lawyers, accountants, financial analysts, and managers are also included in this category.

KNOWN GEOTHERMAL RESOURCE AREA (KGRA)

"Known Geothermal Resource Area" means an area in which the geology, nearby discoveries, competitive interests, or other indicia would engender a belief in men who are experienced in the subject matter that the prospects for extraction of geothermal steam or associated geothermal resources are good enough to warrant expenditures of money for that purpose.

RESEARCH AND DEVELOPMENT

Includes the following types of activities: (a) pursuit of planned research of new knowledge, whether or not the research has reference to a specific application; (b) application of existing knowledge to problems involved in the creation of a new product or process, including work required to evaluate possible uses; (c) application of existing knowledge to problems involved in the improvement of an existing product or process.

SUMMARY OF FINDINGS FROM

THE PERSONAL INTERVIEWS

Draft Copy
7-19-79

Introduction

The personal interview phase of the manpower assessment study was conducted in order to obtain detailed information about development sites, current or potential occupational bottlenecks, emerging occupations, the occupational structure in certain areas of the industry, and additional information that would be helpful in making manpower projections. The interviews were conducted from October of 1978 until February of 1979 and covered thirty-five firms, five of which were included for purposes of training an interviewer. With the exception of the firms included for training purposes, the following is an outline of the criteria used for selecting the participating firms.

Criteria for Selection

The firms selected for personal interview were drawn from the responses to the initial questionnaire mailings. We elected to concentrate only on the private sector because it is in this area that the key decisions will be made determining the growth and needs of the geothermal industry. Also, it appeared that a minimum of thirty to forty firms would have to be interviewed in order to develop an acceptable concensus. Therefore, given our limited resources, the decision was made not to include the government sector and educational institutions.

Based on the preliminary results from the initial questionnaire mailings and upon other information pertaining to the geothermal industry key firms could be identified by their type of activity in the industry and the quantity of manpower devoted to these activities. Hence, one criterion was to try to include a variety of activities, and the other was to interview the firms that were most heavily involved in the geothermal industry in terms of manpower. It was apparent at the time of selection that approximately 10 - 12 firms were the primary employers in the industry. Our subsequent research upholds this as an accurate observation.

Firms involved in supporting services in the industry were not of primary concern in this phase of the study. We felt that the most useful information could be obtained from firms directly involved in a major activity at a geothermal site. Finally, location did not prove to be a useful criterion. Though it appears that most major firms are based in California, their activities are usually conducted at several different sites and often in several different states.

Obviously, the criteria outlined above had to be tempered somewhat. Several important firms would not submit to an interview, and alternate selections had to be made. Table III-1 lists the types of firms interviewed. In some cases the type is quite general and in others a specific activity is given. The designation varied with our knowledge of a given firm and the firm's description of its own activities.

Evaluation of the Personal Interview Approach

In general the interviews yielded less information than we anticipated. Several factors contributed to this result. Some firms were highly reluctant to provide information because they feared it might fall into their competitors' hands, despite our pronounced assurances that all information would remain confidential. For example, a few firms admitted that they had conducted their own internal studies on manpower requirements and other geothermal

TABLE III-1

Firms Included in Personal Interview Phase

Identification Number	Type of Firm and/or Major Activities
1	exploration and assessment (excluding drilling)
2	petroleum
3	electrical utility (construction, operation, and maintenance of power plants)
4	well drilling and drilling services
5	research, development & demonstration of power plants
6	information collection and dissemination
7	well drilling and drilling services
8	exploration and assessment (excluding drilling)
9	electrical utility (R & D of plant design and construction)
10	exploration and assessment (excluding drilling)
11	exploration and assessment (excluding drilling)
12	direct use (agricultural applications)
13	exploration and assessment (excluding drilling)
14	petroleum (exploration and assessment, including drilling)
15	exploration and assessment (including drilling)
16	exploration and assessment (including drilling)
17	exploration and assessment (including drilling) reservoir development, and steam production for electrical power plants
18	well drilling and drilling services
19	exploration and assessment (including drilling)
20	planning power plant construction
21	industrial research and plant design
22	well drilling
23	supporting services for construction sites
24	power plant engineering and design
25	project design and construction management
26	utility (design, construction,and operation of power plants)
27	research and development of reservoir engineering equipment
28	petroleum (exploration and assessment, including drilling)
29	exploration and assessment, plant design, and construction, steam production and transmission
30	exploratory drilling and production drilling
31	exploration and assessment (including drilling)
32	feasibility studies for commercialization
33	exploration and assessment (excluding drilling)
34	electrical utility (power plant construction and demonstration)
*35	exploration and assessment (excluding drilling)

*This firm was dropped from any quantitative analysis because all of its geothermal involvement was in other countries. Other information obtained in the interview is incorporated into the study.

needs but would not allow us to view them. In some cases this was understandable because of the complexities of joint ventures and the rights of proprietary information. However, the major problem appears to be the prevailing uncertainty in the industry. This uncertainty permeates all phases of the industry and includes the broad spectrum of activities ranging from resource definition to the determination of the life of a reservoir. The uncertainty itself emanates from two basic causes. One is due to the infant nature of the industry and the accompanying technological and economic unknowns. The other is institutional constraints to development -- definition of property rights, taxation policies, and regulatory controls -- which must be resolved. In all phases of this study the institutional problems were singled out as the most cumbersome to the growth and development of the geothermal industry.

Another problem with the personal interview approach was the length and detail of the interview guide (see Appendix III-A). This may have contributed to nonresponse to some of the questions and inaccuracies in others. For example, some firms provided 1978 data on the employment summary rather than searching their files for the 1977 data. However, we would like to observe that all the firms interviewed were quite helpful, and most explained why conflicting interests prohibited them from providing more information.

As a final observation it appears that cultivation of the interviewees' interest and involvement by telephone and mail and then a final comprehensive mail questionnaire would have produced equally satisfactory results. Considering the greater expense of personal interviews this is an important insight for future studies.

Results from the Personal Interviews

Response to the various sections of the interview guide ranged from nonexistent to almost 100 percent. For example, not a single firm provided us with their S.I.C. code(s), but on the other hand, all firms but one provided at least a partial estimate of their total or geothermal employment. The following is a short summary of the aggregated responses to each section of the interview guide.

Employment Summary

Table III-2 shows the replies to this section, and Table III-3 shows the ratio of geothermal to total employment. Note that the numerical values are expressed in terms of number of employees rather than in person months.

Geothermal Sites Where the Firm is Involved

Section A (1) yielded comprehensive responses from 23 of the firms interviewed. However, in keeping with our confidentiality pledge, no information which might identify those firms will be presented. Nevertheless, such information was used extensively in developing an overall picture of industry growth.

Problem Occupations

The majority (eighteen) of the firms interviewed anticipated problems in recruiting an adequate workforce. No signigicant pattern based on the type of firm or the size of firm was exhibited in these responses. Comments by the interviewees revealed that shortages of skilled personnel and laborers

TABLE III-2

Employment Summary

Identification Number	Total Employees	Employees Engaged in Geothermal Activities
1	9	9
2	90	24
3	4061	22
4	10	8
5	130	65
6	6	6
7	561	9
8	18	15
9	3500	3
10	30	26
11	2	2
12	53	14
*13	1	1
14	1700	6
15	41	41
16	60	60
17	50	50
18	250	43
19	6	6
*20	6	6
21	-	15
*22	11	11
*23	6	6
24	51	42
25	40	5
26	25,537	253
*27	100	20
28	-	28
29	30	30
30	-	-
31	10	10
32	500	36
33	15,230	16
34	13,024	35
**35	17	17
TOTAL	65,140 (including #35)	940 (including #35)
	65,123 (excluding #35)	923 (excluding #35)

*Firms included for purposes of training the interviewer.

**Deleted from further quantitative analysis because employees were in other countries.

TABLE III-3

Percentage of Geothermal to Total Employment

Identification Number	Percentage
1	100.0%
2	26.66
3	.50
4	80.0
5	50.0
6	100.0
7	1.60
8	83.33
9	.09
10	86.66
11	100.0
12	26.42
13	100.0
14	.35
15	100.0
16	100.0
17	100.0
18	17.20
19	100.0
20	100.0
*21	--
22	100.0
23	100.0
24	82.35
25	12.50
26	.99
27	20.0
*28	--
29	100.0
*30	--
31	100.0
32	7.20
33	.11
34	.27
*35	--

*Insufficient data for computation

could be attributed to either remote development sites or areas of heavy development activities which taxed the local manpower pool, or a combination of the two. The former was viewed as a short-term phenomenon if the activity was a short duration exploration. Geothermal sites in Southern Utah and Nevada were mentioned in this group. The heavy development activities (reservoir completion, power plant construction, and power plant operation and maintenance), posed more serious long-run problems but appeared to be limited to developments at Imperial Valley and The Geysers.[1]

The other category of shortages, scientific and technical personnel, was viewed as a part of an overall national problem. Most firms responding with this concern felt that the geothermal industry was at a considerable competitive disadvantage with the oil and gas industries in recruiting this type of manpower. Reasons given were the uncertainties associated with a new industry and the additional training required to acquaint new personnel with the unique aspects of the geothermal resource.

The following is a synthesis of the information provided in sections A 3(a) and A 3(b) of the interview guide. As previously stated, eighteen firms provided information on A 3(a). Section A 3(b) yielded useful responses

---

[1]Recent assessments of the socioeconomic impacts of proposed geothermal developments in these areas can be found in National Science Foundation, Imperial County California: Geothermal Element, 1975, and in California Resources Conservation and Development Commission, Consultant Report: Environmental Analysis for Geothermal Energy Development in The Geysers Region, Volume II: Master Environmental Assessment, May 1977.

from eleven firms. The problem occupations that were discussed are divided into two groups, primary problem occupations and secondary problem occupations. The primary problem occupations are the ones most often mentioned and viewed as the most serious. The secondary problem occupations were not revealed as being widespread and were generally of a short-run nature.

Primary Problem Occupations

Geologists. There is a pronounced shortage of geologists with experience in hard rocks (granite) and volcanics. Skills in one type of resource (e.g., oil or gas) are not necessarily sufficient for work in the geothermal industry, especially since the geothermal resource itself is not of a homogeneous nature. A master's degree appears to be the minimum requirement, but orientation to the geothermal resource is still necessary.

Geophysicists. The comments directed at geologists also apply to geophysicists. One observer did point out that communication between geologists and geophysicists needs to be improved (e.g., in the area of fault identification).

Reservoir Engineers. The geothermal industry faces stiff competition from the oil and gas industries in the recruitment of reservoir engineers. This problem is compounded by the urgent need in the geothermal industry to improve techniques of reservoir assessment and development in order to reduce the risk to investors.

Environmental Engineers. Although only one firm strongly emphasized this occupation as a current problem (the areas of expertise needed being in discharge of hot fluids, gases, and ground subsidence), it is our conclusion that its potential as a significant bottleneck occupation is considerable. This view is reinforced by the technology assessment portion of this study in which it was pointed out that environmental problems will become more serious as the industry grows, and the various forms of the resource are utilized.

Drill Rig Personnel. The problems here exist from the lowest to the highest skill levels employed at the drilling site. The acquisition of skills and experience and the progression up the job ladder from roustabout, driller assistant, driller foreman, to job foreman is hindered by the nature of drilling work which involves long periods of travel and constant movement to different sites which results in high turnover rates. Recruitment of unskilled labor is basically done by advertising in the work locale and skill acquisition is a function of on-the-job training. A couple of firms did point out that the problem of high turnover rates was much less pronounced in areas where drilling projects were of a long-term nature (e.g., requiring a large number of local wells). Finally, drilling machinists were also mentioned as a problem, essentially because of a lack of qualified mechanics.

In conclusion, it appears that practically all the specifically geothermal related training ranging from the unskilled labor to the scientific and technical personnel is conducted on the job. This was found to be true not only of the occupations mentioned above, but also it is true of occupations that pose little or no constraint on industry growth (e.g., construction, operation, and maintenance of geothermal power plants).

Some training of scientific and technical personnel was received in an indirect manner through research assistantships for graduate students to work on geothermal topics. One other area of training at this level is through short courses of instruction offered periodically by the Geothermal Resources Council. These courses vary and cover a variety of geothermal activities of a technical and a nontechnical nature.

Also, the Oregon Institute of Technology conducted a study in March 1976 which was geared toward assessing the industry's interest in a formal training program in various geothermal activities at the Institute of Technology. The results, by permission from O.I.T., are reprinted as Appendix III-B. However, state funds were not forthcoming to support the program because of the perceived uncertainty of development.[1] Based on our research results, we recommend that the feasibility of such a program be reconsidered, possibly on a federally sponsored basis. One of the major complaints of the firms was that costly on-the-job training was the only way to acquaint scientists and engineers with uniquely geothermal characteristics. The result is that they are less able to compete with the oil and gas industries which can draw recruits from university curricula that favor their specialized needs.

Available evidence tends to support the following observation. It appears that the root cause of the problem in some occupations is that the geothermal industry, in contrast to the oil and gas industries, cannot draw

---

[1] We wish to thank Paul Lineau of O.I.T. for his helpful comments.

on a manpower pool of highly specialized scientific and technical personnel whose training is subsidized by educational institutions. The argument of "parity" in terms of manpower training subsidized by the government has not yet surfaced in the geothermal industry. However, industry spokesmen have strongly argued for "parity" with the oil and gas industries in such areas as tax policy and depletion allowances. Therefore, as the industry grows, the need for specialized manpower may shift it to a higher priority. Our recommendation is that a modest training program at the appropriate institution(s) would go a long way toward removing current and potential occupational bottlenecks that could constrain industry growth.

Secondary Problem Occupations

The following occupations did not appear to be viewed by the respondents as a widespread problem. Instead, they were more unique to a single firm or to a specific locale. However, they are included here for purposes of completeness and future reference.

Mechanical and Electrical Engineers. These personnel are hired at the B.S. level and given the necessary geothermal training on the job. The training is oriented toward drilling, geological, geochemical, and hydrological characteristics applicable to the geothermal resource.

Control Operator. This position requires an ability to operate steam geothermal components and transmission systems. Training is on-the-job and selection for the positions is via very careful in-house screening.

Economics and Finace Personnel. An understanding of the resource and its utilization and unique features is necessary. The general requirement is an M.B.A. coupled with an understanding of geology and energy.

Pipeline Welders. Recruitment is generally through trade schools or advertising in local newspapers. On-the-job training is used to develop skills. The problem (in Southern Utah) has been a shortage of welders certified for pipeline construction.

Heavy Equipment Operators. The problem has been where exploration activities have fluctuated considerably making it impossible to guarantee work for extended periods of time. These personnel are also locally recruited in areas near the development sites.

Pipefitters, Electricians, Iron Workers. Problems in recruitment are limited to The Geysers area and result from competition with other local industries and a limited labor pool at a remote site.

No policy initiatives are recommended for the above occupations because of the relatively isolated nature of their occurrence. The large firms involved at sites with long-run development activities should be allowed to devote their own resources to the problems. In the cases where smaller firms experience recruitment and retention problems the issue appears to be basically the disagreeable nature of the work. The area in which government action might be of help is in streamlining the permitting procedures and other regulations in order to facilitate better planning for continuous activities. This issue is treated by several other studies and will not be pursued here.[1]

New and Emerging Occupations

Ten firms responded to Section A 3(c) concerning new and emerging occupations. As might be expected, many of the occupations discussed have

[1]For example, see Gene V. Beeland, et al, "Geothermal Development on Federal Lands - The Impediments and Potential Solutions", a report prepared for the Development of Energy - Division of Geothermal Energy, January, 1978.

already been identified as posing recruitment and retention problems. Most occupations listed are of a scientific and technical nature. They are also mostly traditional occupations that are becoming specialized to geothermal activities.

Geologists. One area of specialization is in exploration of igneous formations and another is in petrology mapping abilities. Areas of university training that would be helpful are structural vulcanic rocks and in spacial relationships of geothermal aquifers.

Geochemists. Speicalists are emerging with a background in thermal fluids and other areas of groundwater study.

Geophysicists. Needed area of training is hard rocks.

Reservoir Engineers. One specialized area still in its infancy is the design of reservoir facilities. Another is in shallow hole engineering. The position basically will be a hydrologist with a background in geology to help in understanding structural and spacial characteristics of the resource.

Civil, Mechanical, and Electrical Engineers. The speicalization is in the capability to design and monitor systems for waste disposal, emission control, and reinjection.

Chemical Technicians. Skills are composed of the combined areas of hydrology and brine chemistry.

Geothermal Financial Comptroller. There is a need emerging in the geothermal area for individuals well versed in geophysics or geology with an advanced degree in finance (M.B.A.). Peculiarities in the development of geothermal resources (e.g., contracting for the sale of steam and time delays from leasing to reservoir development) have created a new financial and investment framework which requires this type of expertise.

Drilling Personnel. The emphasis on drilling occupations lies in the needed abilities to deal with abrasive rock formations and high temperatures. These conditions have led to technical modifications such as in the fluid medium.

Land Managers. The need for individuals in this area is in part derived from increased government regulation.

Reports Coordinator. Duties are to compile and review regulatory reports. Requirements are a combination of journalistic and technical expertise. This new position is a result of increasing regulatory requirements.

Technical Reports Analyst. Requirements are basically the same as those for the reports coordinator with the impetus for this new occupation also being created by regulatory requirements. Recruitment for both positions is through college campus interviews and press advertisements.

Projection Information and Occupational Profiles

Sections B (1), B (2), B (3), and B (4) were designed to try to find a common denominator in the major geothermal activities in order to make simplified projections of manpower requirements. A total of sixteen firms responded to at least one of the categories. Most of the information applies to only a limited number of sites -- especially Roosevelt Hot Springs, The Geysers, Niland, Brawley, and East Mesa. It must be pointed out that this open-ended format and procedure of investigation as in the final analysis is rather "unscientific" in the sense that participants were not required to reply on the basis of a uniformly given set of general and specific assumptions. In order to make projections for the industry as a whole, the rather limited body of information acquired must be widely applied, admittedly a heroic course of action given the heterogeneous nature of the resource.

Section C was designed to try to develop a picture of the occupational structure in various geothermal activities. We also requested data on the quantity of manpower employed in each occupation and yearly replacement needs. Thirty firms responded to this area of inquiry; however, the quality and usefulness of the responses varied considerably. Some firms only supplied data for 1978. Rather than omit these, we felt that more information would be conveyed by their inclusion with the data being identified by year if it was not 1977 data. In order to be more consistent and to allow some comparisons Section C of the interview guide will be discussed in conjunction with each activity in Section B.

Exploration and Appraisal of the Resource

This activity may be subdivided into two categories denoting the intensity of the efforts involved. First is the "casual use" which is defined by the Bureau of Land Management (Code of Federal Regulations CFR , Title 43, 3209.0-5(d) as "... activities that involve practices that do not ordinarily lead to any appreciable disturbance or damage to lands, resources and improvements. For example, activities which do not involve the use of heavy equipment or explosives." These activities include aerial photo surveys, geochemical and micro-gas surveys, stratigraphic, lithologic, and structural mapping.[1] The second category is the use of more intensive exploration techniques -- e.g., geophysical surveys which include the

[1]U.S. Department of Interior, U.S. Fish and Wildlife Service, Geothermal Project: Geothermal Handbook (June 1976), p. 136.

drilling of shallow temperature holes, or the use of heavy equipment to construct temporary access roads.

One can see that a variety of firms with different types of manpower is required in the exploration and appraisal activity. This resulted in considerable variance in the estimates provided by different firms in our survey. Seven firms addressed themselves to Section B (1), (Estimated number of person months necessary to explore and appraise the resource to the extent that a decision can be made to develop the reservoir at a given site or to abandon development plans), and estimates ranged from three person months to three hundred and sixty person months, depending on the particular phase of activity with which the firm was involved. However, two key firms which were involved in all phases of the exploration and appraisal activity estimated that the total amount of manpower required was 300-360 person months in order to explore and appraise the resoursce to the extent that a decision could be made to develop the resource to given site or to abandon development plans. We consider this to be the most representative estimate since the smaller estimates of other firms reflected their limited role of involvement (e.g., drilling, seismic, and electrical surveys). As will be seen in the next section on drilling, any single estimate to be applied to the industry is highly tenuous because of the different types of energy conversion systems that have to be fitted to the site specific nature of the resource.

Our accepted estimate is somewhat lower that the 1974 Project Independence estimate.[1] However, the latter was based on a differently structured set of assumptions (centered on a 200 MWe plant based on the brine resource)

---

[1] U.S. Federal Energy Administration, Project Independence Blueprint: Final Task Force Report, Geothermal Energy (November 1974). See pages D-1 through D-8.

in order to create building block estimates. The sections of the report which are pertinent to our discussion on occupational structure, occupational requirements, and projections are reproduced as Appendix III-C.

The total number of person months estimated by the Project Independence report as required to explore and appraise the resource (specific assumptions on p. D-4) for a 200 MWe plant was 696 (for two years). However, this included drilling (288 person months) and once this activity is subtracted out, the residual is 408 person months.[1] Since current plants (or those expected in the near future) are no larger than 135 MWe to 160 MWe and since it is reasonable to assume some efficiencies in resource exploration and assessment have been gained in the last few years, we consider our estimate to be quite compatable with that given in Project Independence. However, the reader is cautioned to understand that our estimate is based on current and recent experience of firms while the Project Independence estimate is based on a rigid set of assumptions geared to forecasting the future far beyond our time horizon.

Occupational Profile

The following is a list of occupations and the quantity of persons required on which the Project Independence estimate was based. It is presented for comparison with our survey results for occupational structure only. The quantities of manpower are not comparable because the Project Independence estimate is geared toward completing an activity while ours is geared toward employment by year for given firms. Also, we believe the

[1] It may be somewhat misleading to separate the drilling activity because it is specifically exploratory drilling. Reconsideration of the phrasing of our request B(2) leaves the distinction between exploratory and production drilling quite ambiguous. Fortunately, there are a number of references to drilling requirements, and these will be discussed in the next section.

Project Independence occupational list to be the most comprehensive for comparison with our results.

Occupational Profile from Project Independence

Skill	Quantity Required
Geologist	3
Geophysicist	2
Landman	2
Drill Rig Foreman	4
Drillers	12
Laborers	8
Truck Drivers	4
Geochemists	2

It should be pointed out that many of the occupations which appear on our list as reasearch exploration and assessment appear under the Project Independence heading of reservoir design and development (see Appendix III-C). However, there are other reasons for differences in occupational listings. First, our list is simply an aggregation of the occupations from the several firms interviewed. Therefore, some of the occupations may be considered more of a peripheral nature (derived from the activity but not requiring physical presence at the site). Second, growth of the industry and of the individual firms has led to more occupational specialization. Third, government regulatory requirements have created the need for certain types of expertise (e.g., environmental technicians). The fourth factor is the evolution of technology. The fifth reason is in part a reflection of the previous four but is slightly more abstract. In effect, preliminary investigation (here and elsewhere) hints of a common theme (though as yet quite undefined and not thoroughly explored) in the evolution of occupational structures in energy related industries.[1] The need for research in this area is discussed in the conclusions to the technology assessment phase of our study and need not be repeated here.

In order to convey a more comprehensive picture of the various levels of involvement by the firms in our survey, the occupational structure for each respondent follows the master list of occupations. This pattern will also be repeated in the other activities.

Combined List of Occupations Involved in Resource Exploration and Appraisal

- Geologist
- Geophysicist
- Geochemist
- Mechanical Engineer
- Drilling Engineer
- Petroleum Engineer
- Engineering Technician
- Computer Analyst
- Data Processing
- Contracting/Purchasing
- Financial Anaylst
- Accounting
- Legal
- Bookkeeper
- Manager
- Land Manager
- Land Draftsman
- Land Secretary
- Draftsman
- Drilling Supervisor
- Exploration Technician
- Environmental Technician
- Secretaries

[1] A limited descriptive investigation can be found in U.S. Department of Labor, Bureau of Labor Statistics, Bulletin 2005, Technological Change and its Labor Impact in Five Energy Industries (April 1979).

Identification Number	Occupations Most Strongly Related to Geothermal Activities	Total Number of Persons Employed September 1977	Total Number of Person Months September 1977	Yearly Replacement Needs
*1	Chief Geologists	1	12	**--
	Land Managers	2	24	--
	Chemists	1	12	--
	Mechanical Engineer	1	12	--
	Engineer Technician	1	12	--
	Accountant	1	12	--
	Manager	1	12	--
	Bookkeeper	1	12	--
	Legal Staff	1/3 to 3/4	4-9	--
	Contracting/Purchasing	1/3 to 3/4	4-9	
	Rounded Total	11	126	
8	Geophysicists	3	-	-
	Data Processing	1	-	-
	Computer Analyst	1	-	-
	Draftsperson	1	-	-
	Field Geologist	2	-	-
	Field Technician	3	-	-
	Geologist(well logging)	1	-	-
	Field Chief (geologist)	2	-	-
	Field Programmers	1	-	-
	Technician	1	-	-
	Total	16	Personnel are used 90-100% in geothermal	

* 1978 data

**If blank, then no information was provided

III

Identification Number	Occupations Most Strongly Related To Geothermal Activities	Total Number Persons Employed Sept. 1977	Total Number of Person Months Sept. 1977	Yearly Replacement Needs
10	Geophysicists	10	-	-
	Geologists	10	-	-
	Environmental Tech.	8	-	-
	Total	28	Used 85% of the time in geothermal	
16	Land Use Personnel	5	60	-
	Geophysicists	25	-	-
	Geologists	5	-	-
	Total	35		
*17	Geologist	3	-	-
	Geochemist	1	-	-
	Draftsman	4	-	-
	Landman	4	-	-
	Environmental Planner	2	-	-
	Drilling Engineer	1	-	-
	Administrative Engineer	1	-	-
	Field Superintendent	3	-	-
	Other	5	-	-
	Total	24		

*1978 Data

Identification Number	Occupations Most Strongly Related to Geothermal Activities	Total Number of Persons Employed Sept. 1977	Total Number of Person Months Sept. 1977	Yearly Replacement Needs
19	Geologist	2	24	-
	Geophysicist	1	12	-
	Drilling Engineer	1	6	-
	Petroleum Engineer	1	6	-
	Mechanical Engineer	1	3	-
	Land	2	18	1
	Legal	1	6	-
	Total	9	75	1
33	Geologists	3	36	-
	Geophysicists	2	24	-
	Geochemists	1	12	-
	Manager	1	12	-
	Draftsman	2	24	-
	Land Manager	1	12	-
	Land Secretary	1	12	-
	Land Draftsman	1	12	-
	Financial Analyst	1	12	-
	Exploration Tech.	2	24	-
	Drilling Supervisor	1	12	-
	Attorney	2	3-12	-
	Accounting Staff	2	3-12	-
	Secretaries	2	12	-
	Rounded Total	22	230	

Reservoir Design and Development

This activity may include additional deep well exploratory drilling, but most drilling is geared toward production and reinjection wells. Also, surface structures such as steam gathering systems are included.

Number of Wells Required to Prove Feasibility of Energy Production

As was previously mentioned section B (2) -- (Estimated number of wells necessary to prove the reservoir for scheduled energy production or other activity, estimated average well depth and estimated yearly average of replacement wells) -- was somewhat ambiguous as to whether it was directed strictly toward exploratory wells, production wells, or both. Having reviewed other studies (to be cited below) it became a simple task to separate the two.

Nine firms responded to section B (2). One firm responded that only one well was required to prove a hot dry rock reservoir. Little can be said about the additional drilling needed to develop the hot dry rock resource because it is still in the early experimental stages. Other firms responded that for some reservoirs at The Geysers only 2-3 wells were required. This is consistent with the estimate given (1-5 deep exploratory wells) in the Geothermal Project: Geothermal Handbook (p. 142). Additional estimates provided by the Handbook are that a crew of 4-6 is required for ten days of drilling per well or a crew of 20-24 working around the clock for 1/3 the time, based on a well of approximately 10,000 feet in depth. (p. 142). The Handbook assesses the drilling rate for geothermal wells to be between 100-200 feet per 24 hour day (p. 22). Finally, it should be pointed out that drilling depths in many cases are not reflective of what is required to tap the resource but what is economically feasible. For example, depths of 12000 - 15000 feet are estimated to be required to reach the geopressured resource, but the maximum explorable depth is approximately 11,000 feet (1976 estimate given by the Geothermal Handbook, p. 21).

Another document which provides estimates pertaining only to The Geysers estimated test drilling to require 45-60 days.[1] Most wells at The Geysers were assessed at depths of 7000-8000 feet. The Consultant Report stated that 10-15 wells were required to support a 110 MWe plant (p. I-C-14) with as many as 25 wells when reserve and reinjection wells are counted. Ninety percent of the wells drilled were said to be successful with the remainder used for reinjection (p. IV-D-2).

Additional information from our survey was as follows. One firm estimated the average number of production wells required to support a 55 MW_e power plant was eleven plus two reinjection wells and three reserve wells. This firm did not provide average depth estimates. Four other firms estimated the average number of wells necessary to prove a reservoir for production to be respectively -- 14, 8-10, 11, and 10. Replacement wells were estimated to be required every 1-3 or 1-5 years by these firms. It should be pointed out that each of these latter four firms provided estimates based on their experience at The Geysers while the estimate provided by the first firm for a 55 MW_e plant was considered an average of different sites with which the firm was involved. Average well depths were reported by seven firms and ranged from 3,400 feet to 14,000 feet.

---

[1] California Energy Resources Conservation and Development Commission, Consultant Report on Environmental Analysis for Geothermal Energy Development in the Geysers Region, Volume II, Master Environmental Assessment, prepared by Stanford Research Institute (May 1977), P. I-C-5. A later description of a drilling rig crew is that it consists of four drilling company emplyees and eight others either from local unions or transient roustabouts (p. V-D-6).

It is obvious that much of the above information is questionable especially since it will be used in a forecasting model. Hopefully, it will elicit critical comments that will contribute toward its refinement. If so, it has served a useful purpose.

Given below is the occupational profile for production drilling from Project Independence for a 200 MW_e dry steam plant assuming 34 wells (providing 20% spare capacity), 60 work days per well (average), five rigs, and an average depth of 5000 feet. Afterwards the information obtained from our study is presented.

Occupational Profile from Project Independence

Skill	Quantity Required
Rig Foreman	4
Driller	16
Pipe-Fitter	4
Welder	2
Crane Operator	1
Truck Driver	2
Laborer	12

Occupational Profile for Drilling Firm

Three firms provided information in this category. No new types of personnel were needed for geothermal drilling.

Assistant Driller

Driller

Drilling Foreman

Job Foreman

Derrickman

Motorman

Identification Number	Occupations Strongly Related to Geothermal Activities	Total Number of Persons Employed Sept. 1977	Total Number of Person Months Sept. 1977	Yearly Replacement Needs
*7	Assistant Drillers	9	-	6
	Driller Foreman	9	-	6
	Job Foreman	9	-	.5
	Total	27		12.5
18	Drilling Foreman	4	-	-
	Driller	4	-	-
	Derrickman	4	-	-
	Motorman	4	-	-
	Drilling Helper	8	-	-
	Total	24		
*22	Drillers	4	9	-
	Driller Helpers	8	9	-
	Total	12	18	

*1978 data

Manpower Requirements for the Reservoir Feed System

Five firms responded to Section B (3) -- (Estimated number of person months required to construct the reservoir feed system and the estimated average number of person months required to operate and maintain the reservoir feed systems for one year) -- The only useful information provided concerning the construction of a feed system was that as a rule of thumb the manpower requirements were approximately 25% of the total requirements for constructing a power plant. Operation requirements of the feed system were estimated to be 1-4 full time individuals with some major maintenance tasks being contracted out.

Despite the sparse information provided it does appear to have been rather accurate in the sense that it fits quite well into the Project Independence list of occupations and number of persons required. We were provided with no occupational profile in this category so we can only reprint the Project Independence profile based on a 200 MW_e dry-steam plant (including design requirements).

Occupational Profile from Project Independence
Construction of Gathering System

Skill	Quantity Required
Mecanical Engineer (Design)	2
Civil Engineer (Design)	1
Draftsman (Designer Quality)	1
Draftsman	1
Route Surveyor	5
Civil Engineer (Construction)	1
Foreman	2
Welder	4
Carpenter	2
Concrete Worker	4
Dozer-Operator	2
Truck Driver	4
Crane Operator	2
Insulation Installer	6
Inspector (Construction)	1
Inspector (testing)	2

Operation and Maintenance of Gathering System

Skill		Quantity Required
Field Operator	operation	2
Foreman		1
Pipefitter		2
Welder		1
Insulation Installer	maintenance	2
Crane Operator		1

As can be seen the 1-4 required personnel for operation and maintenance of the gathering system is quite compatable with the above estimate, especially when one considers that current and near future developments are considerably less than 200 MW_e. Also, if one examines the quantity of personnel required for construction of the power plant (to be discussed next) as estimated by Project Independence the ratio of construction requirements for the gathering system to construction requirements for the power plant is 23.58 percent.

Construction of Power Plants

Ideally this activity should also include the construction of transmission lines, but we obtained no information on this subject. However, the Consultant Report (p. I-F-3 and I-F-5) stated, "construction of the transmission lines for one generating unit [at The Geysers] requires about 8 months ... The transmission line crews vary from 10 to 30 workers and are drawn from PG & E's Line Construction Department."

Seven firms responded to section B (4) -- (Estimated number of person months required for power plant construction and/or direct use facility construction and the estimated average number of person months required to operate and maintain the facility for one year) -- with all but one being involved in power plant construction.[1] The manpower needs for construction of a 10 MW_e demonstration plant were estimated to be 35-40 persons for ten months. Estimated requirements for construction of 50 MW_e plants ranged from 2,400 to 4,800 person months. The wide variance in manpower requirements could partially reflect the more intensive efforts needed to commercialize the geothermal resource as it is used in its more marginal (i.e., less productive) forms, especially in the transition from dry steam to hot water. Again, the 2,400 - 4,800 estimate proves to be compatible with the <u>Project Independence</u> estimate (3882 person months) based on a three year phased construction program (See Appendix III-C).

---

[1]This exception stated that it took 1 1/2 - 2 years to construct a facility (for raising hogs) based on one reservoir and that operation/maintenance of the reservoir required one person while the agricultural duties required 4-5 people.

Occupational Profile from Project Independence

Power-house:

Assume: a) 2-100 MWe (net) Generating Units
b) 1.5 year design schedule
c) 3 year constr. sched.
d) 24 mo. deliv. sched. on each T/S set

Skilled Personnel	Quantity Required
Struct. Engineer	2
Mech. Engineer	5
Civil Engineer	2
Elec. Engineer	3
Corrosion Engineer	1
Architect	2
Draftsman (Designer Qual.)	4
Draftsman	16
Topog. Surveyor	5
Purchasing Agent	1
Inspector (Equip.)	2
Corrosion Engineer	1
Civil Engineer (Construction)	2
Mech. Engineer	1
Elec. Engineer	2
Surveyor (Constr. control)	4
Inspector (Constr.)	3
Superintendent (Constr.)	1
Asst. Super. (Constr.)	1
Foreman	6
Electrician	6
Pipe Fitter	10
Welder	8
Millwright	6
Iron-Worker	6
Concrete Worker	15
Sheetmetal Worker	6
Carpenter	10
Plumber	4
Insulation Installer	4
Tile-Setter	2
Painter	4
Instrument Technician	3
Machinist	2
Rigger	8
Truck Driver	5
Crane Operator	4
Timekeeper	1
Warehouseman	3
Pile-Driver	4
Laborer Common	20

The first three occupational profiles pertaining to power plants from our personal interview survey is a mixed result because these firms were involved in various stages of reservoir completion, power plant design and engineering. However, the fourth profile is more representative of occupations required for construction activities.

Occupational Profiles for Reservoir Development, Power Plant Engineering, and Design

Identification Number	Occupations Strongly Related to Geothernal Activities	Total Number of Persons Employed September 1977	Total Number of Person Months Sept. 1977	Yearly Replacement Needs
5	Environmental			
	Geologist	2	-	-
	Area Planner	1	-	-
	Air Qality Tech.	1	-	-
	Noise Pollution	1	-	-
	Archeologist	1	-	-
	Engineers			
	Mechanical	4	-	-
	Process (Mining/metals)	1	-	-
	Management			
	Manager	1	-	-
	Lawyer	1	-	-
	Procurement Spec.	1	-	-
	Administrative	6	-	-
	Secretarial	4	-	-
	Comptroller	12	-	-
	Asst. Comptroller	12	-	-
	Total	48		

Identification Number	Occupations Strongly Related to Geothermal Activities	Total Number of Persons Employed September 1977	Total Number of Person Months Sept. 1977	Yearly Replacement Needs
24	Mechanical Engineers	8	-	-
	Technical Assistants	3	-	-
	Chemical Processing Engineers	2	-	-
	Plant Design	1	-	-
	Architect	3	-	-
	Electrical Engineers	9	-	-
	Project Manager	2	-	-
	Civil/Structural Engineer	3	-	-
	Instrumentation	1	-	-
	Total	32		
29	Head Geologist	1	12	-
	Staff Geologists	5	60	-
	Geological Draftsman	1	12	-
	Drilling Head	1	12	-
	Drilling Engineer	1	12	-
	Tool Pushers	2	24	-
	Mechanical Engineers	1	12	-
	Geological Engineer	1	12	-
	Production Foreman	1	12	-
	Construction Foreman	1	12	-
	Contract Support People	2	24	-
	Pipeline Technician	3	36	-
	Reservoir Engineer	1	12	-
	Land Manager	1	12	-
	Comptroller	3	36	-
	Landman	1	12	-
	Total	26	312	

Occupational Profile for Construction Activities for Commercial Power Plants (approximately 50 MW_e)

(Includes multiple plant activities at The Geysers)

Identification Number	Occupations Most Strongly Related to Geothermal Activities	Total Number of Persons Employed September 1977	Total Number of Person Months Sept. 1977	Yearly Replacement Needs
26	Project Superintendent	1	12	0
(operator)	Engineers	21	227	4
	Inspectors	12	155	2
	Clerical	16	185	2
	Total	50	579	8
(contractors)	Superintendents, Clerical, Engineers	10	65	-
	Boilermakers	2	2	-
	Carpenters	50	169	-
	Electricians	15	62	
	Pipefitters	5	18	
	Ironworkers	10	38	
	Laborers	22	163	
	Millwrights	2	6	-
	Operators	27	227	
	Teamsters	8	38	-
	Total	151	723	

The following two quotes and the figure on page III-36 lend a more descriptive flavor of the manpower requirements for the construction of a geothermal power plant (Specific reference is for The Geysers).

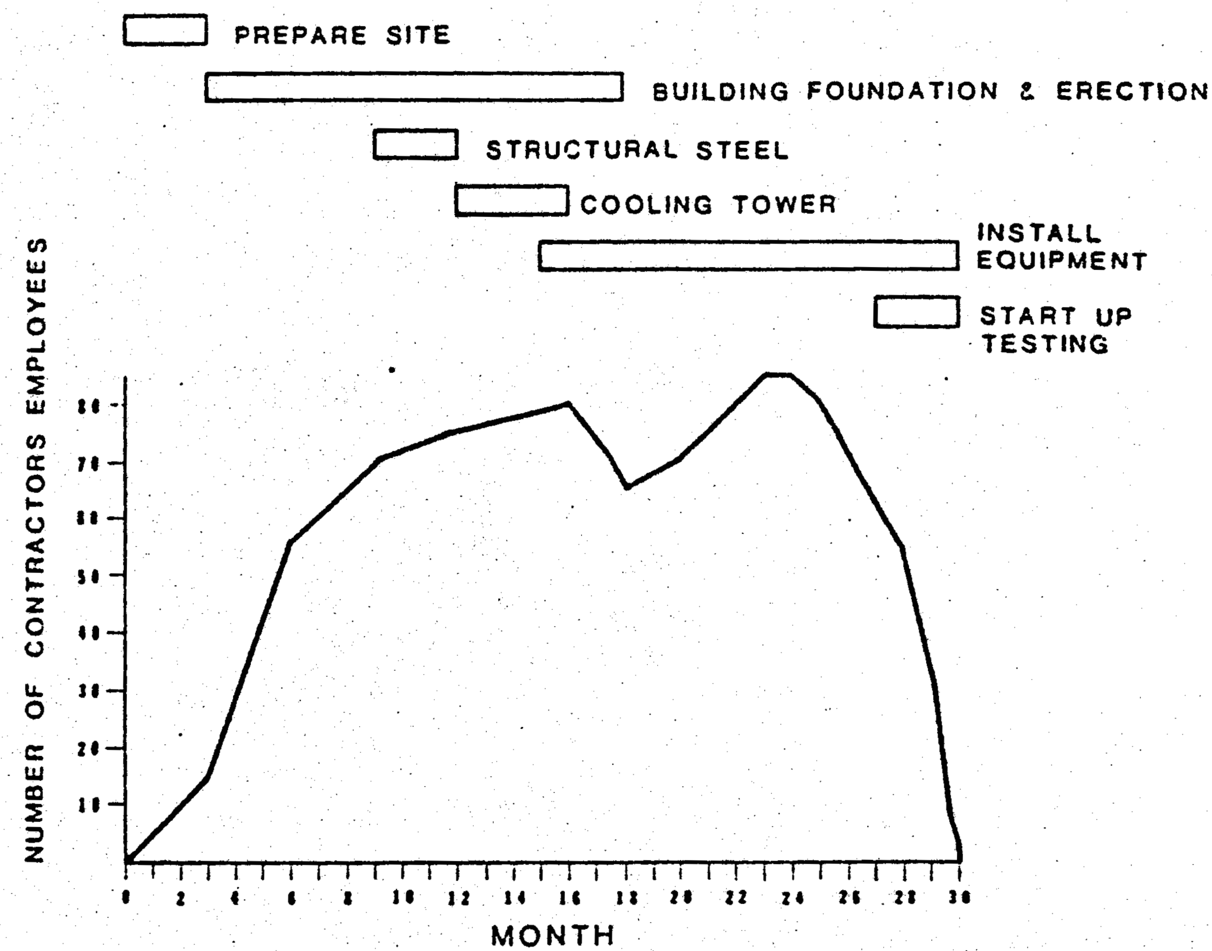
> The work force for any one unit will vary depending on what phase of the project is being done. The clearing and grading crews are relatively small, whereas during excavation, there may be as many as 40 workers on the site. Once construction of the generating unit and cooling towers begins, the number of construction workers may rise to 60 or 70. The number of workers will decrease during the final phases (see Figure I.F.1).

The activities at the generating unit site are handled by contractors. As many as 20 subcontractors may be used on any job, but not more than five at one time. Each subcontractor will have a pick-up truck on the job and will visit the work site from time to time, probably once a week. Workers for the current field normally either live at the existing construction camp near Units 3 and 4 in Sonoma County or commute. Construction activities have been continuing for so many years at The Geysers Power Plant that a large labor force lives in the general area. Some workers may commute temporarily from the Middletown and Lakeport areas.

(Consultant Report, pp. I-F-4 and I-F-5)

Construction activities have been continuing for so many years in The Geysers area that a large labor force associated with these activities lives within the general area. Additional construction jobs are provided for local equipment operators, welders, surveyors, loggers, and construction laborers during the earth-moving stages for roads and pads. The work force for each plant varies, depending on the phase of the project being constructed. The clearing and grading crews are relatively small. During excavation, there are somewhere between 40 and 50 workers on site. Once construction of the unit and the cooling towers begins, the number could increase threefold. The total number of construction laborers involved simultaneously in various geothermal development sites varies, depending on the number of units being constructed and the schedule for building.

(Consultant Report, p. I-F-8)



SOURCE: Pacific Gas and Electric, 1975 [143].

FIGURE I.F.1 ESTIMATED TYPICAL SCHEDULE AND SIZE OF WORK FORCE

Source: California Energy Resources Conservation and Development Commission, Consultant Report on Environmental Analysis for Geotherman Energy Development in the Geysers Region: Volume II: Master Environmental Assessment, prepared by Stanford Research Institute, page I-F-2.

Operation and Maintenance of Power Plants

The Project Independence report also in this activity assumes a 200 MWe dry-steam plant. Note that the report's estimate is for 41 persons for a 200 MWe plant while the estimate provided to us for the entire operation and maintenance requirement at The Geysers was only 52.

Occupational Profile from Project Independence

Skilled Personnel		Quantity Required
Plant superintendant (oper.)	Operation	1
Shift Foreman	Operation	3
Plant operator	Operation	9
Mech. Engr. (Turb. Specialist)	Routine Maintenance	1
Corrosion Engineer	Routine Maintenance	1
Instrument Technician	Routine Maintenance	2
Foreman	Routine Maintenance	2
Millwright	Routine Maintenance	4
Machinist	Routine Maintenance	2
Pipefitter	Routine Maintenance	3
Welder	Routine Maintenance	2
Electrician	Routine Maintenance	3
Insulation Installer	Routine Maintenance	2
Painter	Routine Maintenance	2
Rigger	Routine Maintenance	3
Crane Operator	Routine Maintenance	1
Laborer		

We were able to obtain the occupational structure for both 10 MWe demonstration plants and for the commerical plants at The Geysers. The operation and maintenance estimates for a demonstration plant for a year were 224-300 person months per year, and the figures for a 50 MWe commercial plant were 100-360 person months.

Operational Profile of the Operation and Maintenance of a 10 MW_e Demonstration Plant

Identification Number	Occupations Most Strongly Related to Geothermal Activities	Total Number of Persons Employed September 1977	Total Number of Person Months Sept. 1977	Yearly Replace-ment Needs
*5	Assistant Control Operator Technicians	8	-	-
	Professional Chemist	1	-	-
	Chemical Technicians	3	-	-
	Electrician	1	-	-
	Welder	1	-	-
	Machinist	1	-	-
	Instrument Technicians	2	-	-
	Supervisor Technician	1	-	-
	Total	18		

Occupational Profile for Operation and Maintenance of a Commercial Power Plant
(Includes multiple plant activities at The Geysers)

Identification Number	Occupations Most Strongly Related to Geothermal Activities	Total Number of Persons Employed September 1977	Total Number of Person Months Sept. 1977	Yearly Replace-ment Needs
26	Machinist	11	-	1
	Electrician	8	-	-
	Instrument Repairman	4	-	-
	Welder	2	-	-
	Rigger	2	-	-
	Helper	6	-	1
	Control Technician	1	-	-
	Senior Power Plant Operator	2	-	-
	Power Plant Operator	12	-	-
	Assistant Power Plant Operator	4	-	-
	Total	52		2

Although there were a number of other respondents to this part of the interview guide, those not already discussed were only partially involved. For example, several petroleum companies, electrical utilities, research firms, and construction firms responded, but their activity was basically that of an observer or their involvement in the industry was only a very small part of their overall or primary activities. Also, their listing of occupations contains none that have not already been covered. Therefore, omission of these firms from further consideration in this section does not leave out any useful information.

Total Employment Trends

The purpose of Section D was to get simplified estimates of direction and magnitude of geothermal employment. It should be emphasized that this approach is highly restrictive since respondents are likely to operate on different sets of assumptions. Also employment trends derived from this approach will not include new firms that enter the industry. Table III-4 shows that some firms provided estimates for years other than those requested. These are included but so designated in the Table.

The trend suggested by these results is that the part of the geothermal industry represented by these firms has grown significantly (in terms of persons employed) since 1970. Nothing substantial can be stated about the 1985 totals since only a few firms were willing to speculate beyond 1980. A relatively small number of firms also responded to the request for 1970 data, but it is reasonable to assert that considerably fewer firms were involved in the industry at that time. The following are the totals of employment in the four years, first with the data for the nonrequested years being deleted and second, with this data being included (n = number of firms responding in this column).

Table III-4

Estimate of Total Geothermal Employment (Number of Persons) by Year and the Percent of Geothermal to Total Employment

Identification Number	1970 # of Persons	1970 % of Total	1975 # of Persons	1975 % of Total	1980 # of Persons	1980 % of Total	1985 # of Persons	1985 % of Total
1	*		1		12			
2								
3	0		15	.4	25	.4	65	1.2
4			8	75	20	80		
5	15 (1976)	30 (1976)	55 (1977)	42 (1977)				
6								
7	0	0	9					
8	9		12		14			
9	1	.0005	3	.0009	1	.0003	13	.0029
10			10	100	33	65		
11			2 (1978)		7			
12								
13			1		0		0	
14			1 (1977)		5		5	
15			41	100	41	100		
16	10 (1971)	100 (1971)	50	100	85	100		
17			25	100		100		100
18			22 (1976)	9 (1976)				
19	1	50	6	100	12	100	24	100
20	0	0	3	100				
21								
22					6	100		
23			7	25				
24	15	20	15	50				
25			15 (1978)	12.5 (1978)	150			
26	9		55		163		250	
27	0	0	20	20	20	20	20	20
28			19	100	59	100	106	100
29		100	30	100	42	100	57	100
30								
31								
32								
33	4 (1973)		9		11			
34	4 (1972)		4					

*Blank spaces indicate that no information was provided.

Total Number of Persons Employed in Geothermal Activities
(excluding data pertaining to nonrequested years)

Year	1970	1975	1980	1985
	35	317	665	540
	n=5	n=20	n=17	n=8

Total Number of Persons Employed in Geothermal Activities
(including data pertaining to nonrequested years)

Year	1970	1975	1980	1985
	49	446	665	540
	n=7	n=28	n=17	n=8

Firms Involved in Research and Development

The attempt here was to gain some understanding of the number of firms involved or totally dependent on research and development activities. Table III-5 reproduces these results. It appears that nothing very significant stands out except perhaps that two of the firms that are 100 percent into research and development are known to us as large utilities which are trying to commercialize novel techniques.

TABLE III-5

Research and Development Activities

Identification Number	Percent of Geothermal Activities in Research and Development
1	0
2	*
3	100
4	0
5	100
6	
7	0
8	
9	100
10	
11	
12	0
13	0
14	
15	
16	
17	0
18	0
19	0
20	0
21	100
22	0
23	0
24	0
25	
26	
27	100
28	
29	15
30	0
31	
32	
33	0
34	

*Blank indicates no response.

Conclusion

One of the main contributions of this part of our study has been the identification of occupations that are currently or are expected to be constraints on industry growth. These were geologists, geophysicists, reservoir engineers, environmental engineers, and drilling rig personnel. The first four occupations are better viewed as part of a national problem with several different industries competing for a limited availability of this type of manpower. Those surveyed in this part of our study explained that the geothermal industry is at a competitive disadvantage (especially as compared to the oil and gas industries) in bidding for new job market entrants and experienced personnel. The crux of the problem appears to be the lack of courses specifically related to the geothermal resource in scientific and engineering curricula. In effect these industry "spokesmen" are asking for subsidized training considerations comparable to those given to the oil and gas industries.

Our recommendation is for the feasibility of government supported training courses on a modest scale (in one or a few universities) to be considered. If the geothermal industry is truly at a competitive disadvantage, this action should be a step toward removing this institutional barrier and letting the industry freely seek its own level as a demander in the labor market.

The last occupational group, drilling personnel, has widespread problems (e.g., high turnover) due to the nature of the job (e.g., extended hours, frequent travel, and remote work sites). Direct government actions are not recommended due to the character of the problem. However, a streamlining of government regulations that would facilitate better planned drilling efforts might lead to more stability.

The second main contribution of the personal interviews has been the information gained for manpower forecasting purposes. This was used extensively in the formulation of a forecasting model which is discussed in the next section.

APPENDIX III-A

Interview Guide

OMB. No. 38-S-78013
Approval Expires June 30, 1979

III 41

INTERVIEW GUIDE

Sponsor: U.S. Department of Energy

Divisions of Manpower
Assessment and Geothermal Energy

Survey Conducted by: Human Resources Institute
University of Utah
Salt Lake City, Utah 84112

INTRODUCTION

A select number of key organizations for the development of the geothermal industry will be interviewed by the Human Resources Institute for the purposes of:

(1) assessing and forecasting manpower requirements, and

(2) identifying and defining occupational bottlenecks and emerging occupations in the industry.

Your firm has been selected and given approval to participate in this personal interview survey. We ask your help in supplying the information requested on the following pages. We have designed the interview questionnaire in hopes that it will require minimal time commitment. All sources of data and information obtained in the interview will be held strictly confidential, and any published information will not permit identification of the source.

INTERVIEW GUIDE

Company ______________________________ SIC Code(s) ________

Address ______________________________

____

____

____

Official's Name and Title ______________________________

Telephone No. ______________________________

EMPLOYMENT SUMMARY

What was the total number of employees in your organization in the payroll period which included September 12, 1977? (Include all employees whether or not engaged in geothermal related activities). ____________

Of this total, how many were engaged in geothermal activities? ____________

A. Unless otherwise indicated, participation at a geothermal development site should be interpreted as a direct use of manpower at the physical site.

This survey is basically concerned with forecasting to the 1985 target date; however, if activities in the 1985-1990 period can be foreseen, they should also be given consideration.

(1) Please identify the sites (KGRAs) at which your firm is presently participating or plans to participate in geothermal development.

Site (KGRA)	Resource Type	Development Activity	Beginning Date	Ending Date	Estimated Manpower Requirements (in person months)

(2) Do you anticipate any problems in recruiting an adequate (in quantity and/or quality) work force for these projects?

Yes ______ No ______ Unable to judge ______

(3) a. If yes, please indicate the particular occupation(s) with which you anticipate difficulties:

Problem Occupation(s)	Sources of Difficulty -- e.g., Remoteness of Site Location, Lack of Labor Market Information, Competition with other Industries, Etc.

ailed analysis of occupations that may cause difficulties.

Job Title	Job Description	Training and/or Education Requirements	Changes in Job Requirements During the Last Five Years	Expected Future Changes Induced by Technology or Other Factors	Sources of Supply	Method of Recruitment

(3) c. If new occupations or significant modifications of common ones are emerging in your geothermal field, please analyze via the matrix below. If the occupations are still too poorly defined to formalize into the matrix, a brief discussion of a more qualitative nature (on reverse side of page) will still be of great help.

Job Title	Job Description	Training and/or Education Requirements	Changes in Job Requirements During the Last Five Years	Expected Future Changes Induced by Technology or Other Factors	Sources of Supply	Method of Recruitment

8. Given the chemical and physical characteristics of the site(s) with which your firm is associated, please answer the questions which are relative to your given type of development activity. Please indicate the site associated with each reply.

(1) Estimated number of person months necessary to explore and appraise the resource to the extent that a decision can be made to develop the reservoir at a given site or to abandon development plans. Include remote sensing, surface surveys, and subsurface techniques inclusive of exploratory drilling.

Site (KGRA)	Person Months

(2) Estimated number of wells necessary to prove the reservoir for scheduled energy production or other activity, estimated average well depth, and estimated yearly average of replacement wells.

Site (KGRA)	Number of Wells	Average Well Depth	Yearly Average of Replacement Wells

(3) Estimated number of person months required to construct the reservoir feed system and the estimated average number of person months required to operate and maintain the reservoir feed systems for one year.

Site	Requirements for Constructing the Feed System	Requirements to Operate/ Maintain the System for One Year

(4) Estimated number of person months required for power plant construction (include demonstration and commercial plants) and/or direct use facility construction and the estimated average number of person months required to operate and maintain the facility for one year.

Site	Power Plant		Direct Use Facility	
	Construction	Operation/ Maintenance	Construction	Operation/ Maintenance

C. In order to make estimates of future demand by occupation in the geothermal industry, the following information is needed to establish baseline data. If possible, response should be based on data available as of September 1977.

(1) Please list the specific occupations which are most heavily involved in geothermal-related activities in your organization.

(2) For each occupation listed, please indicate the actual number of persons employed and the total number of person months.

(3) If possible, please provide an estimate of the yearly replacement needs for each occupation listed based on your organization's recent experiences. Yearly replacement needs can be defined as the number of persons per occupation that were hired to fill positions vacated by retirements, quits, layoffs, deaths, etc. during the year ending September 30, 1977. Do not include new hires attributable to industry growth.

Occupation	Total Number of Persons Employed as of Sept.'77	Total Number of Person Months as of Sept.'77	Yearly Replacement Needs

D. Estimate of total geothermal employment (number of persons) for the following years and the percent of geothermal to total employment.

1970		1975		1980		1985	
# of persons	% of total	# of persons	% of total	# of persons	% of total	# of persons	% of total

E. What percent of your organization's total geothermal activities is in geothermal research and development? ______________________

F. Any written information that your company has that could be supplied describing your manpower structure would be a valuable contribution to our effort (e.g., manning tables, job descriptions, labor/management contracts).

APPENDIX III-B

Results from The Oregon Institute of Technology Survey

III

OREGON INSTITUTE OF TECHNOLOGY
Objectives and Courses of Study
for
Proposed Associate of Engineering and Bachelor of Technology Programs
in
Geothermal Engineering Technology

Objectives of the Program

1. To train technologists to work in the field of geothermal energy.

   a. Geothermal Exploration and Reservoir Assessment Technology

      The technologist will be able to:

      --Supervise field exploration crews in the field;
      --Take samples for laboratory analysis and perform the necessary field preparation for storage and shipment;
      --Perform the analytical chemistry techniques that must be done in the field;
      --Supervise the layout instrumentation placement and operation for geophysical exploration;
      --Supervise test hole drilling and logging;
      --Perform field recovery and logging of core samples;
      --Perform and supervise production well logging by all applicable techniques;
      --Gather data for ground water studies, perform geological mapping and sampling;
      --Prepare reports to the supervising geophysicists or hydrologist; and
      --Prepare impact statements for exploration and assessment activities.

   b. Geothermal Well Completion and Utilization Technology

      The technologist will be able to:

      --Specify and supervise installation of well casing and well head equipment;
      --Under the direction of a registered engineer, perform design and supervise installation of vapor and fluid transmission piping systems including separators and silencers, pumping equipment, heat exchange equipment of all types, pollution control equipment and procedures, instrumentation and controls; and
      --Perform field engineering, supervise maintenance work, prepare reports for his supervisors, and write impact statements related to the application of geothermal energy.

GEOTHERMAL TECHNOLOGY QUESTIONNAIRE

1. How many positions per year would you expect your company to have that could be filled by geothermal graduates?

   Associate (2 year) Degree Graduates 6

   Bachelor (4 year) Degree Graduates 28

2. Do the curriculum objectives as stated fit your company's needs?

   Exploration YES 15 NO 3

   Utilization YES 14 NO 3

3. How would you change the objectives if not suitable as stated?

   Most of the comments here were on either the "saleability" of grads or that more rigorous math, science, and especially geology courses were needed. Several felt the stated objectives were overstated compared to the course work.

4. Do the courses listed in the curriculum fit the objectives?

   YES 24 NO 3

Comments:

Generally good.

5. Which, if any, of the additional courses listed would you like to see in the curriculum?

More

Geology	- 13	48%
Hydrology	- 4	15%
Chemistry	- 5	19%
Thermo	- 5	19%
Geophysics	- 4	15%
Legal	- 3	11%

Several listed one other course (mixed)

6. Which, if any, courses listed in the curriculum would you suggest omitting or reducing in credit hours?

Supervision	- 6	22%
Social Science	- 6	22%
Psychology	- 4	15%
Machanics	- 2	7%
Elec. Machines	- 2	7%

7. Would your organization be willing to send a representative to the OIT campus to discuss the curriculum?

YES 2 NO 10 ? 3

Most didn't check either way.

8. General comments:

Four responses were highly in favor of the program. Three were not in favor of the program; either there was no need or the courses did not fit company needs. Three offered crop program possibilities.

APPENDIX III-C

Occupational Profiles from *Project Independence*

PART D

Geothermal Manpower Estimates

This section presents the assumptions and factors used to estimate the manpower requirements for geothermal. Two types of geothermal energy processes are presented: (1) dry-system and (2) brine or hot water. The manpower estimates were prepared by Bechtel Corporation for use in the FEA Project Independence Blueprint exercise.

The manpower "building-block" estimates were developed around an assumed economically viable geothermal producing field having an installed capacity of 200 MWe. To compute total manpower requirements the manpower building-block estimates presented in this section are multiplied by the number of plants derived for each by year for the accelerated and business-as-usual scenario as shown in Table 2 and 3.

Manpower Est., Brine and Dry Steam
General Assumptions and Factors
200 MWe (Net) Plant

I. Utility companies are presently demanding that the 20 percent excess capacity be developed in the geothermal field as a hedge against uncertainty and premature failure of wells. This may not be required in the 1980's with better knowledge of the energy source. Manpower estimates presented on the following pages for (a) reservoir design and development and (b) gathering systems should have been increased by 20 percent for this excess capacity requirement.

II. Manpower estimates for clerical and administrative personnel represent 5 percent of total manpower personnel.

Manpower Est. Brine Resource (Only)
All Phases of Development
200 MWe (net) Plant

1. Scope of Work:

All phases of development of a hot-brine resource for production of electrical energy including:

a) Resource Exploration and appraisal
b) Reservoir design and development
c) Conversion system design and construction
d) Operation and maintenance

II. Assumptions:

a) Manpower requirements for exploration, and discovery of dry-steam resources will be twenty (20) times that required for the same capacity of brine resource.

b) Manpower requirements for reservoir design and development will be proportional to the required number of wells, and will be the same for either dry steam or brine resources.

c) Manpower requirements for the conversion system design and construction of a brine-type power plant will be 40% greater than for a dry-steam plant.

d) Manpower requirements for operation and maintenance of a brine plant will be at least 25% higher.

e) For each 200 MWe plant there will be:

52 development wells
26 re-injection wells

assuming water temperature of 382 degrees - 200 psi.

III 6

Dry Steam Plant Model

Manpower Est. Brine Resource (only)
Resource Exploration and Appraisal,
200 MWe (net) Plant

Scope of Work:

Conduct initial gross reconnaissance to identify prospects; conduct local geological/geophical investigations to discriminate among prospects and identify specific resource to be developed; develop necessary rights and leases to permit physical development; sink necessary exploratory wells to determine chemical and thermal properties of the geothermal fluid.

Assumptions:

1. Explore 4 prospective areas to find 1 desirable prospect (Physical measurement).
2. Drill 16 drillable prospects to find 1 field of 200 MW electric minimum initial capacity.
3. Average well capacity is 5 MWe per well.
4. Drill 2 exploratory holes per drilled prospect.
5. Take 60 calendar days per exploratory hole.
6. Have 4 drill rigs drilling for 18 months.
7. Twenty-four month exploration and drilling program to find 200 MWe.

Manpower (In Man Years)
Resource Exploration & Appraisal

Quantity Required	Skill	1st Yr	2nd Yr
3	Geologist	3	3
2	Geophysicist	2	2
2	Landman	2	1
4	Drill rig foremen	2	4
12	Drillers	6	12
8	Laborers	4	8
4	Truck Drivers	2	4
2	Geochemists	1	2

III 61

Manpower Est., Dry-Steam Resource (Only)
Reservoir Design & Development
200 MWe (Net) Plant

Scope of Work:

Construct reservoir model; locate and drill all production wells and all reinjection wells; perform well-logging and preliminary well tests; case, cement, and complete all wells thru the well-head valves to complete shut-in. Conduct well-flow tests, chemical sampling, etc.

Assumptions:

a) Total initial production wells = 34 wells (provides 20% spare capacity)
b) Drilling time = 60 work days/well (average)
c) Working drill rigs = 5 (average)
d) Average well depth = 5000 ft.

	Quantity Required	Skilled Personnel	Man Years (1.0 yr.) 1st yr.	Man Years (0.2 yr.) 2nd yr.
Reservoir Modeling	1	Reservoir Engineer	.75	0
	1	Geologist (Theoretical)	.3	0
	1	Geophysicist	.3	0
	1	Hydrologist	.3	0
	1	Geochemist	.3	0
	1	Mathematician (Applied)	.75	0
	1	Mathematical Technician	.75	0
	1	Draftsman	.25	0
	2	Geologist (Core-Logger)	2.0	0.4
	1	Drilling Superintendent	1.0	0.2
Well Drilling (Four Crews)	4	Rig Foreman	4	0.8
	16	Driller	16	3.2
	4	Pipe-Fitter	4	0.8
	2	Welder	2	0.4
	1	Crane Operator	1	0.2
	2	Truck Driver	2	0.4
	12	Laborer	12	2.4
Well Test (One Crew)	1	Reservoir Engineer	0.75	0.2
	2	Mech. Engineer	1.50	0.4
	1	Geochemist	0.75	0.2
	2	Mechanical Technician	1.50	0.4

Manpower Est. Dry-Steam Resource (Only)
Design & Construct Conversion System
200 MWe (Net) Plant

Scope of Work:

Design, procure, construct, test, and start-up the entire above-ground plant, whose limits extend from the well-head valve discharge flange thru the gathering and reinjection system, thru the power generation plant, and thru the switch-yard. It does not include any electric power transmission facilities.

I. Gathering System:

Assume:
a) 34 producing wells
b) 34,560 ft. pipe 16" thru 36"
c) 1 year design, procure, and construct. program 4 mo. design, 8 mo. constr.
d) well-head valve to last centrif. separator.

Quantity Required	Skilled Personnel	Man Years Total
2	Mech. Engineer (Design)	0.7
1	Civil Engineer (Design)	0.33
1	Draftsman (Designer Quality)	0.33
1	Draftsman	0.33
5	Route Surveyor (0.25)	1.25
1	Civil Engineer (Construction)	0.7
2	Foreman (0.7)	1.4
6	Pipe Fitter (0.5)	3.0
4	Welder	2.0
2	Carpenter	1.0
4	Concrete Worker	2.0
2	Dozer-Operator	1.0
4	Truck Driver	2.0
2	Crane Operator	1.0
6	Insulation Installer (864 wk)	0.5
1	Inspector (construction)	0.58
2	Inspector (non-destruct. testing)	0.60

II. Power-house:

Assume:
a) 2-100 MWe (net) Generating Units
b) 1.5 year design schedule
c) 3 year constr. sched.
d) 24 mo. deliv. sched. on each T/S set

Quantity Required	Skilled Personnel	1st yr.	2nd yr.	3rd yr.
2	Struct. Engineer	2.0	1.0	-
5	Mech. Engineer	5.0	2.5	-
2	Civil Engineer	2.0	1.0	-
3	Elec. Engineer	3.0	1.5	-
1	Corrosion Engineer	0.3	-	-
2	Architect	0.5	0.2	-
4	Draftsman (Designer Qual.)	4.0	2.0	-
16	Draftsman	11.5	4.0	-
5	Topog. Surveyor	3.3	-	-
1	Purchasing Agent	0.5	0.5	-
2	Inspector (Equip.)	1.0	1.0	-
1	Corrosion Engineer	0.2	-	0.2
2	Civil Engineer (Construction)	2.0	2.0	2.0
1	Mech. Engineer	1.0	1.0	1.0
2.	Elec. Engineer	2.0	2.0	2.0
4	Surveyor (Constr. Control)	4.0	4.0	1.0
3	Inspector (Constr.)	3.0	3.0	3.0
1	Superintendent (Constr.)	1.0	1.0	1.0
1	Asst. Super. (Constr.)	1.0	1.0	1.0
6	Foreman	5.0	6.0	5.0
6	Electrician	4.0	6.0	6.0
10	Pipe Fitter	-	-	10.0
8	Welder	4.0	8.0	6.0
6	Millwright	3.0	6.0	4.0
6	Iron-Worker		6.0	4.0
15	Concrete Worker	1.5	1.5	7
6	Sheetmetal Worker	-	3.0	6.0
10	Carpenter	10	10	4
4	Plumber	-	-	4
4	Insulation Installer	-	2.0	4
2	Tile-Setter	-	-	1.5
4	Painter	-	3.0	4.0
3	Instrument Technician	-	1.5	3.0
2	Machinist	-	2.0	2.0
8	Rigger	1.3	4.0	3.0
5	Truck Driver	5.0	5.0	4.0
4	Crane Operator	3.0	4.0	3.0
1	Timekeeper	1.0	1.0	1.0
3	Warehouseman	1.0	3.0	2.0
4	Pile-Driver	4.0	-	-
20	Laborer Common	15.0	20.0	10.0
		15.1	15.2	23.5

Manpower Est. Dry-Steam Resource (Only)
Operation & Maintenance
200 MWe (Net) Plant

I. Scope of Work:

Operate and maintain the entire energy recovery system and conversion system thru the 35 year design life of the 200 MWe plant. Assume 2 wk. planned outage/yr. + 30 day planned outage each 3 years, for each unit.

II. Powerhouse:

	Quantity Required	Skilled Personnel	Average Man Years Per Year of Plant Life
Operation	1	Plant superintendant (oper.)	1
	3	Shift Foreman	3
	9	Plant Operator	9
Routine Maintenance	1	Mech. Engr. (Turb. Specialist	0.1
	1	Corrosion Engineer	0.1
	2	Instrument Technician	0.5
	2	Foreman	0.2
	4	Millwright	0.2
	2	Machinist	0.2
	3	Pipefitter	0.3
	2	Welder	0.2
	3	Electrician	0.2
	2	Insulation Installer	0.2
	2	Painter	0.2
	3	Rigger	0.1
	1	Crane Operator	0.1
		Laborer	0.2

III. Gathering System:

	Quantity Required	Skilled Personnel	Average Man Years Per Year of Plant Life
Oper.	2	Field Operator	1
Routine Maint.	1	Foreman	0.1
	2	Pipefitter	0.2
	1	Welder	0.1
	2	Insulation Installer	0.2
	1	Crane Operator	0.1

1	Civil Engineer (Design)	
1	Mech. " (")	
1	Draftsman	
1	Civil Engineer (Constr.)	0.2
1	Foreman	0.5
3	Pipefitter	1.5
2	Welder	1.0
2	Carpenter	0.5
4	Conc. Worker	0.1
1	Dozer Operator	0.2
1	Crane Operator	0.2
1	Truck Driver	0.5
2	Insulation Installer	0.5
1	Inspector (Constr.)	0.1

III 6

Bibliography

California Energy Resources and Conservation Commission. Consultant Report on Environmental Analysis for Geothermal Energy Development in the Geysers Region: Volume II, Master Environmental Assessment by Stanford Research Institute. May 1977.

National Science Foundation. Imperial County California: Geothermal Element. 1975.

U.S. Department of Labor, Bureau of Labor Statistics. Technological Change and Its Labor Impact in Five Energy Industries (Bulletin 2005). April 1979.

U.S. Federal Energy Administration. Project Independence Blueprint: Final Task Force Report, Geothermal Energy. November 1974.

U.S. Department of Energy, Division of Geothermal Energy. "Geothermal Development on Federal Lands - The Impediments and Potential Solutions" by Gene Beeland, et. al. January 1978.

U.S. Department of Interior, Fish and Wildlife Service. Geothermal Project: Geothermal Handbook. June 1976.

MANPOWER FORECAST

Draft

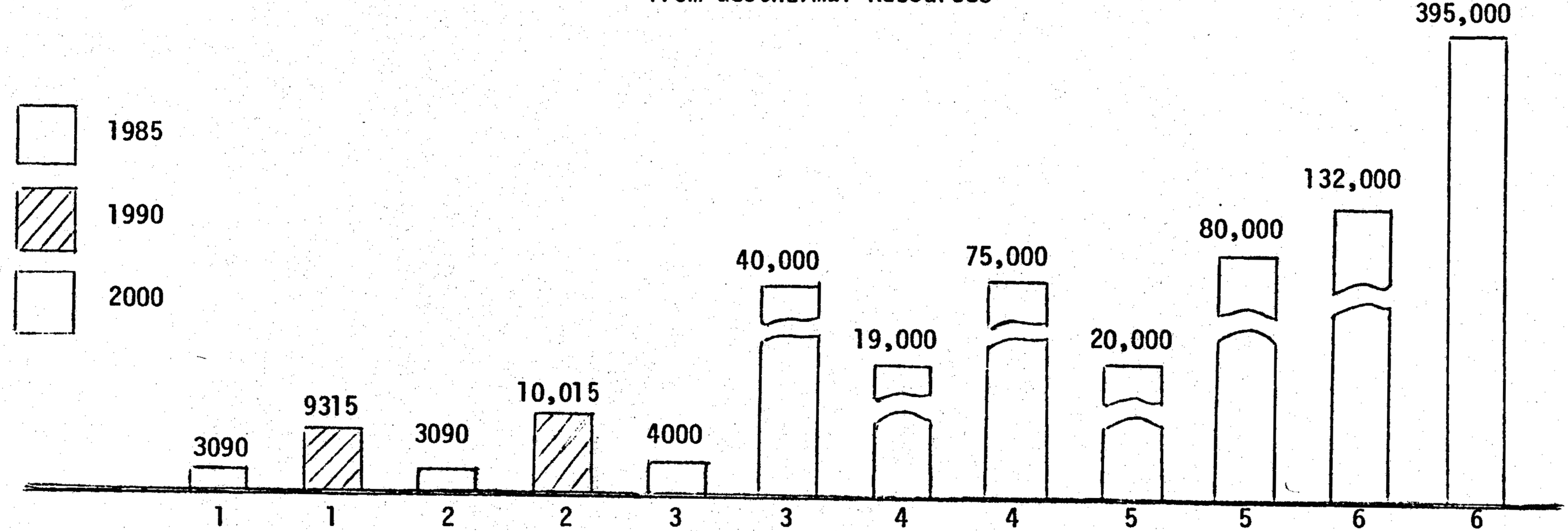
Introduction

Based on the information we have obtained from the personal interview phase of the manpower assessment study and upon the other sources available, the following procedure was used to forecast manpower growth in the geothermal industry. Note that this forecast is only for that segment of the industry which encompasses electrical energy production. To date the direct use geothermal activities are largely undefined. This may be a serious shortcoming in assessing the industry's growth and potential uses since direct use is the most efficient application of the resource. Therefore, we have developed a crude employment multiplier for that segment of the industry which is not engaged in commercial production of electicity. Despite the uncertainties that attend the forecast and the application of the multiplier, this is a necessary first step in the development of a clearer picture of this relatively unknown segment of the industry.

Electrical Energy Growth Scenario

The first task was to identify the most likely growth scenario for the industry. Forecasted potential growth in the industry has drastically declined from the highly optimistic extremes of a few years ago. The illustration on the next page demonstrates this point. As time has passed, more realism has crept into the assessments and expectations of the resource. Although the more recent estimates are more compatible than earlier ones, differences may still be in the neighborhood of several hundred megawatts. Given the small base of industry output (e.g., 502 MW_e in 1977) as a point of reference, it is obvious that differences of this magnitude are considerable in percentage terms and would affect manpower estimates accordingly.

Estimates of MW_e to be Generated from Geothermal Resources



[1]U.S. Department of Energy, Interagency Geothermal Coordinating Council, Third Annual Report: Geothermal Energy, Research, Development & Demonstration Program (March 1979), p. XI.

[2]U.S. Department of Energy, Interagency Geothermal Coordinating Council, Second Annual Report: Geothermal Energy, Research, Development & Demonstration Program (April 1978), p. 5-6.

*[3]U.S. Bureau of Mines Analysis, 1973.

*[4]U.S. Department of Interior, "Assessment of Geothermal Energy Resources, 1972."

*[5]"The Nation's Energy Future," a report to the President of the United States, submitted December 1, 1973, by the Chairman, A.E.C.

*[6]W.J. Hickel, Geothermal Energy, 1972.

*The references are given as cited in U.S. Congress, Senate, Petroleum Industry Involvement in Alternative Sources of Energy, Publication No. 95-54, 95th Congress, 1st Session, 1977, p. 61.

Most sources have forecasted no additional commerical production except at The Geysers until 1983.[1] However, there is disagreement as to how much power will come on line at The Geysers during 1979, 1980, 1981, and 1982. The installed capacity was 502 MW_e at The Geysers in 1977, approximately 608 MW_e in 1978, and approximately 908 MW_e by the end of 1979. We consider the best estimate through 1980 to be 971 MW_e based on information released by the California Energy Commission and the best estimate for 1981 to be 1301 MW_e.[2] These estimates appear to be more reasonable than 1288 MW_e and 1453 MW_e for 1980 and 1981 respectively which were given by the Energy Research and Development Agency, Division of Geothermal Energy.[3] The rationale for this conclusion is that the latter overestimated the Geysers' output by approximately 165 MW_e for 1978 and approximately 105 MW_e for 1979. Estimates have been updated in 1978 and 1979 reports by the Department of Energy's Interagency Geothermal Coordinating Council (IGCC), but the forecasts begin with the year, 1983.[4] This required the use of the other sources thus far mentioned.

The IGCC's scenario (as used in the 1979 report) is used beginning with 1982 (when 1680 MW_e are forecast for The Geysers) and progressing through 1990. Although there are other (differing) estimates of industry growth, they are not as specific as that of the IGCC. Also, as the

---

[1] An exception in given by Robert Rex, who projects installed capacity at The Geysers to be 1733 MW_e by the end of 1983 and additional installed capacity to be 138 MW_e at Imperial Valley and 50 MW_e at Roosevelt Hot Springs, Utah for the same year. See Robert W. Rex, "The U.S. Geothermal Industry in 1978," paper presented at the Geothermal Resource Council's Special Short Course No. 7, Geothermal Energy: A National Opportunity (The Federal Impact), Washington, D.C. (May 17-18, 1978).

[2] Ibid.

[3] U.S. Energy Research and Development Agency, Division of Geothermal Energy, First Annual Report: Geothermal Energy Research, Development and Demonstration Program (April 1977), p. 110.

[4] U.S. Department of Energy, Interagency Geothermal Coordinating Council, Second Annual Report: Geothermal Energy, Research, Development & Demonstration Program (April 1978), and Third Annual Report: Geothermal Energy, Research, Development & Demonstration Program (March 1979).

uncertainties increase the further we are trying to peer into the future, the evaluation of the underlying assumptions that lead to differing estimates becomes more tenuous. The one qualification that can be made is that other estimates are lower and that the results of our personal interview phase indicate that the IGCC scenario is likely to be optimistic.

Assumptions

The complete development scenario on which our forecast is based is given as Appendix IV-A. With very few exceptions it appears that all increments in generating capacity will be either 50-55 MW_e single turbine-generator systems or dual systems counted as a 100-110 MW_e unit. This limitation on the size of a generating unit is mostly the result of constraining reservoir characteristics (e.g., well placing and limitations on distance from wellhead to the generating unit).

Since most of the manpower data available to us (via our personal interview survey and other sources) are predicated on the completion of a 50-55 MW_e facility, a convenient building block exists. However, there is the problem of economies of scale if one is discussing units greater than 55 MW_e. Intuition may lead one to conclude that a 100 MW_e unit will require less manpower in all (or some) phases of development than two 50 MW_e units.. This has some appeal in the short run; however, we will see different types of generating systems required over the next ten years -- i.e., multiple flash and binary systems -- which may require more intensive manpower use than current dry steam systems. Application of new technology may allow the development of what are currently considered less productive reservoir systems, but on the other hand there is no guarantee that manpower requirements will be reduced or that economies of scale will be realized with larger units. This is but one example of a number of "countervailing uncertainties" in the future development of the geothermal industry. Therefore, we have elected to assume that the manpower requirements for units significantly larger than 50 MW_e are simply a linear multiple of the requirements for the 50 MW_e unit.

During the course of our investigation into the geothermal industry (especially pertinent is the personal interview survey) we have been provided with various estimates as to the technical limitations and manpower requirements in various activities.[1] In most cases respondents provided an interval estimate. Based on this format we believe that a minimum and a maximum manpower requirement schedule can be constructed. In effect this process has only decreased the uncertainty of our estimate to the extent that we have increased the range. As more information becomes available in the future, the estimated range of requirements and the margin of error should be decreased.

The nature of the information available to us was quite useful in forecasting gross employment. However, an employment forecast of a more specific nature presents a number of additional technical problems which will be discussed later. Also, our knowledge of particular occupations is supplemented somewhat from the views of employers concerning current and expected scarcities in certain occupations. This discussion can be found in the personal interview segment of this report and in the conclusion of the technology assessment.

The following is the set of additional general assumptions underlying

---

[1]For detailed explanation see the Summary of Findings from the Personal Interviews.

the forecasting model.

(1) The pace of development of electrical energy production will proceed as outlined under the previous section, Electrical Energy Growth Scenario. See Appendix IV-A for complete details.

(2) The occupational structure of the industry and of individual firms will not be radically altered from its current status by demand or supply considerations, or by technological change.

(3) Technology will neither speed up nor slow down the various activities involved in bringing a power plant on line or in operating and maintaining a power plant.

(4) There are no ecnomies or diseconomies of scale either with different sizes of power plants or with power plants based on different resource characteristics.

(5) Current or proposed changes in regulatory requirements will neither increase nor decrease the pace of development.

As previously discussed the specific assumptions follow the development of low and high estimates of requirements for various activities.

Low	High
(1) 300 person months are required to explore and asses the resource to the extent that a decision can	(1) 360 person months (same explanation and qualifications as for the low estimate).

Low	High
be made of whether or not to develop the reservoir. This excludes drilling activities, but includes such efforts as aerial surveys, seismic surveys, and resistivity surveys.	
(2) The minimum well depth requirement is 7000 feet.	(2) The maximum well depth requirement that is economically feasible is 14,000 feet.
(3) The maximum drilling rate is 200 feet per 24 hour day.	(3) The minimum drilling rate is 100 feet per day.
(4) The minimum requirement to operate and maintain a drilling rig 24 hours per day is 20 persons.	(4) The maximum requirement to operate and maintain a drilling rig 24 hours per day is 24 persons.
(5) 23.33 is the minimum person months required per 7000 foot well. (7000'/200' = 35 days and 35 days * 20 persons = 700 person days which if divided by 30 days = 23.33 person months).	(5) 112 person months is the maximum required per 14,000 foot well (14000'/100' = 140 days and 140 days * 24 persons = 3360 person days which if divided by 30 days = 112 person months).
(6) The same requirements exist for exploratory <u>and</u> production wells.	(6) The same requirements exist for exploratory <u>and</u> production wells.

Low	High
(7) The minimum number of exploratory wells needed is one.	(7) The maximum number of exploratory wells needed is five.
(8) The minimum number of production wells needed for a 50 MW_e plant is ten. Therefore, the requirement in person months would be 23.3 * 10 = 233.3.[1]	(8) The maximum number of production wells needed for a 50 MW_e plant is twenty-four. Therefore, the requirement in person months would be 112 * 24 = 2688.
(9) The minimum requirement for power plant construction (50 MW_e) is 2400 person months.	(9) The maximum requirement for power plant construction (50 MW_e) is 4800 person months.
(10) The manpower requirement in person months for construction of the reservoir feed system is 25% of the requirement for construction the power plant (i.e., 2400 * .25 = 600).	(10) Same requirement as the minimum estimate (i.e., 4800 * .25 = 1200).
(11) One person (12 person months) per year is required to operate and maintain the reservoir feed system.	(11) Four persons (48 person months) per year are required to operate and maintain the reservoir feed system.
(12) 80 person months are required to construct the transmission lines for a 50 MW_e plant.	(12) 240 person months are required to construct the transmission lines for a 50 MW_e plant.

[1]We have not built into the model a method of including replacement wells. This is an extremely difficult area to quantify. However, our range of estimates should be sufficiently broad to take this factor into account.

(13) 100 person months per year are required to operate and maintain a 50 MW_e plant.

(13) 360 person months per year are required to operate and maintain a 50 MW_e plant.

The Forecast

Total Growth in Employment

Using person months as the common unit of measurement the minimum and maximum total requirements for new plants can now be calculated for 1985 and 1990.

Total Manpower Requirements for 1980 through 1985 Forecasted Growth (new plants)[1]

Estimated output in MW_e for 1985 is 3090. Using 1979 as the base year in which output is expected to be 908 MW_e, the difference is 2182 MW_e. If 50 MW_e is used as the building block unit of measurement, approximately 43.6 generation units will be required (either singly or combined).

The computation of the minimum manpower requirement in person months for each 50 MW_e unit is as follows.

300	(resource exploration and assessment)
23.3	(exploratory drilling)
233.3	(production drilling)
2400	(power plant construction)
600	(feed system construction)
12	(operation and maintenance of feed system)
100	(operation and maintenance of power plant)
+ 80	(transmission lines construction)
3748.6	

[1]Note that we have excluded demonstration plants from our analysis. The reason for this decision is in part because the only information we were able to obtain on demonstration plants concerns operations and maintenance. However, the stronger argument lies in the "abnormal" manpower structure these plants require because of their experimental nature, the legal limitation on the length of time they can operate, and on their limited size, 5-10 MW_e. Exclusion of this category only deletes 2-3 plants from analysis.

The maximum manpower requirement in person months for each 50 MW_e unit is as follows.

360	(resource exploration and assessment)
560	(exploratory drilling)
2688	(production drilling)
4800	(power plant construction)
1200	(feed system construction)
48	(operation and maintenance of feed system)
360	(operation and maintenance of power plant)
+ 240	(transmission lines construction)
10,256.	

Therefore, the total manpower needs in order to have 3090 MW_e on line in 1985 will be in the range -- 163,438.96 person months and 447,161.6 person months, caclulated as follows.

3748.6 * 43.6 (power plants) = 163,438.96

10,256. * 43.6 (power plants) = 447,161.6

Dividing by 12, the above figures are converted to a full-time equivalent number of workers. The range in this case is 13,620 - 37,263. Note that this is a considerable underestimate in the actual number of persons involved in the industry. This is especially true when considering: (1) The ease of substitution of drilling rigs between the geothermal, oil, and gas industries, (2) the uniform requirement for constructing electrical transmission lines which allows the use of the same personnel to perform this task regardless of the power source, and (3) the general ability of many firms to switch personnel from geothermal to other activities (and vice versa) as the need arises. Also, responses from many individuals responding to our mail survey indicated a large number of persons associated with the industry only on a part-time basis.

Total Manpower Requirements for 1986 to 1990 Forecasted Growth (new Plants)

The increment in the number of 50 MW_e plants including 1986 through 1990 is 124.5. Using the same computations as in the previous section the minimum requirement is estimated to be 3748.6 * 124.5 = 466,700.7 person months and the maximum requirement to be 10,256 * 124.5 = 1,276,872, or 38,892 to 106,406 persons (with the same qualifications as above that this would be a downward biased estimate).

Total Manpower Requirements for 1980-1990 Forecasted Growth (new plants)

The total number of 50 MW_e plants required in this period is 168.1. This implies an estimated total manpower growth requirement during this period to be ...

minimum 3748.6 * 168.1 = 630,139.6 person months

maximum 10,256 * 168.1 = 1,724,033.6 person months

or 52,512 - 143,669 as a downward biased estimated range of total persons required.

Net Growth in Employment

Very little information was obtained concerning the replacement needs of the industry, except in the drilling activity in which turnover was quite high. Therefore, we have assumed replacement needs to be zero in our forecast. Due to the nature of the relatively small size of the industry (in terms of output and employment) and the short time horizon of our forecast, we do not view this as an unreasonable assumption.

Another observation is that the construction activities were not mentioned as a problem area (in contrast to the breakdown of the labor market infrastructure in some locales associated with the coal boom in the area. One report states, "Construction activities have been continuing for so many years at The Geysers power plant that a large labor force lives in the general area."[1]

Second, geothermal power plants are quite small (e.g., 50 MW_e) compared to a coal fired power plant complex (e.g., 750 MW_e). The accompanying manpower requirements are therefore much lower and produce socio-economic impacts of a much smaller magnitude. The impact is of course much greater in areas where multiple plant developments will be concentrated, for example, in Imperial Valley.[2]

Third, as are all power plants, the geothermal plants are subject to a number of regulatory screenings and controls which slow down the development process. Currently, the requirements seems to be a minimum of 4 1/2 years from initial exploration to finalized construction of the power plant. This should provide ample time for planning manpower availability and efficient utilization.

In connection with this third factor we did not attempt to time phase the manpower requirements. The reasoning is that this would only serve to unduly complicate the forecast, especially since various sources are not only in disagreement on the amount of power to come on line in the future, but also in disagreement of when and where plants will come on line.

---

[1] California Resources Conservation and Development Commission, Consultant Report: Environmental Analysis for Geothermal Energy Development in the Geysers Region, Volume II: Master Environmental Assessment (May 1977), p. V-D-10.

[2] See, Geothermal Element: Imperial County California, National Science Foundation Grant No. AER-75-08793,

There are two areas which can be given special consideration in determining the net employment requirements that will be generated by industry growth. The first is that we can judiciously assume that the manpower required to put a given output on line in a benchmark year will carry over into succeeding years and can therefore be subtracted from the total requirements. The second is operations and maintenance personnel which will become a fixed requirement with the physical facilities once they are established.[1]

The first area of special consideration is perhaps more arbitrary, but we view it as necessary in the effort to produce more accurate estimates. We have chosen 1978 as a base line year of employment. In order to meet the forecasted output for this year an addition of 300 MW_e must be made over the 1978 output which was 608 MW_e. In our building block estimate of 50 MW_e plants this addition will therefore require the capability in terms of manpower of developing six new units. We will therefore subtract this "existing" manpower base from the 1985 and 1990 total estimate of manpower requirements in order to produce the net requirements. Recall that we have assumed replacement requirements to be zero throughout the eleven year period including 1980-1990.

Given our choice of a base year to assess the existing manpower stock in order to arrive at net future requirements, we have included Table IV-1 so the reader can understand the discrete changes in output as forecasted for each year and how our choice compares with other years. However, note that a few

---

[1]This obviously excludes maintenance work that is contracted for as needed.

TABLE IV-1

Year	Forecasted (or achieved) Output in MW_e	Percentage Change from Previous Year
1977	502	--
1978	608[1]	21.0
1979	908[1]	49.3
1980	971[2]	6.9
1981	1301[1]	34.0
1982	1680	29.1
1983	2190	30.4
1984	2410	10.0
1985	3090	28.2
1986	3690	19.4
1987	4815	30.5
1988	6115	26.9
1989	6815	11.4
1990	9315	36.7

[1] Estimate provided by the Geothermal Energy Institute.

[2] California Energy Commission estimate. All other estimates are from the Interagency Geothermal Coordinating Council's Third Annual Report (March 1979).

months delay (or advancement) of the power-on-line schedule for a few plants might greatly alter the percentage estimates for certain years.

Before subtracting the "existing" manpower base from total requirements the second consideration, operation and maintenance personnel, must be discussed. It is reasonable to assume that each new plant and feed system will require a complete operation and maintenance staff that generates an equivalent number of new hires in the industry. Therefore, since this part of the manpower stock can not be carried over into the future plants, it must be deducted from the total stock for the base year.[1] The computations are as follows.

Existing Manpower Stock (in person months) for 1979 (i.e., capability to bring six 50 MW_e power plants on line).

Minimum		Maximum
300.	(resource exploration/assessment)	360.
23.3	(exploratory drilling)	560.
233.3	(production drilling)	2688.
2400.	(power plant construction)	4800.
600.	(feed system construction)	1200.
12.	(operation/maintenance of feed system)	48.
100.	(operation/maintenance of power plant)	360.
+ 80.	(transmission lines construction)	+ 240.
3748.9		10256.
- 112.	(combined operation/maintenance personnel)	- 408.
3636.6		9848

3636.6 * 6 (power plants) = 21,819.6   9848 * 6 = 59,088

[1]Of course highly skilled individuals are indeed moved from one plant to another, and less skilled individuals are carefully screened for training programs that enable them to move into higher positions at new plants or existing plants. However, even if occupational growth in the industry can be managed through the internal labor market, the demand will still be forthcoming for the new hires at the bottom of the skill ladder.

These minimum (21,819.6) and maximum (59,008) estimates can be deducted from the total manpower requirements for 1985 and 1990, but a final assumption must be made. We assume that six power plants can be brought on line with existing capabilities by 1985 and that an additional six plants can be brought on line by 1990. Therefore, in the 1980-1990 time frame it follows that existing manpower is capable of bringing twelve plants on line. We can now compute the estimates for net employment gains in our forecast.

Net Employment Gains 1980 - 1990 (person months)

Minimum		Maximum
163,438.96	(total forecasted employment in person months)	447,161.6
- 21,819.60	(1979 capability in person months to bring six power plants on line by 1985)	- 59,088.
141,619.36	(net gain in person months)	388,073.6

Net Employment Gains 1986 - 1990 (person months)

Minimum	Maximum
466,700.7	1,276,872.
- 21,819.6	- 59,088.
444,881.1	1,217,784

Net Employment Gains 1980 - 1990 (person months)

Minimum		Maximum
630,139.6		1,724,033.6
- 43,639.2	(for 12 power plants)	- 118,176.
586,500.4		1,605,857.6

As has been previously explained, the conversion of person months to expected full-time new hires by dividing by twelve will be a considerable underestimate of the total number of people that are likely to be employed in the industry, because of part year employment and fluctuation between thermal and nonthermal activities. The reader is urged to keep this qualification in mind in examining the following figures.

Net Employment Gains 1980 - 1985 (new hires)

Minimum	Maximum
11,802	32,339

Net Employoemnt Gains 1986 - 1990 (new hires)

Minimum	Maximum
37,073	101,482

Net Employment Gains 1980 - 1990 (new hires)

Minimum	Maximum
48,875	133,821[1]

[1]Totals may not be completely consistent due to rounding.

The Application of Multipliers

We have used the broader empirical analysis derived from the mail survey to develop a general multiplier for additional employment generated in the industry based on on-site development activities (see pages II-35 and II-36). Note that this is not a secondary employment multiplier (meaning not directly attached to the industry) but instead reflects additional employment that is directly involved in geothermal activities. These activities may include such categories as investment, legal, and research and development. However, it is important to keep in mind that many "employees" themselves may also be attached to other industries and only involved in the geothermal industry on a part-time basis.

The magnitude of the multiplier which we calculated is 1.6. That is, for every employee at the development site, 1.6 employees are needed that are not directly attached to the development site. Thus, in order to estimate the full impact of employment within the industry, we can apply the multiplier to the net employment gains which were calculated in the last section. With the same restrictions holding, the total industry employment estimates are as follows:

Total Industry Employment Gains 1980-1985 (new hires)

Minimum	Maximum
30,685	84,081

Total Industry Employment Gains 1986-1990 (new hires)

Minimum	Maximum
96,390	263,853

Total Industry Employment Gains 1980-1990 (new hires

Minimum	Maximum
127,075	347,935

It is important to keep in mind that the above estimates are a separate avenue of approach from the forecast by specific occupational groups in Appendix IV-B. The latter does in part compensate for the variety of occupations which are not directly connected with on-site developments. The multiplier approach is used here because it is quite compatible with our estimated on-site requirements to bring a power plant on line.

Secondary employment multipliers are perhaps the most uncertain. The smaller scale of field development, power plant construction, and operation and maintenance activities in the geothermal industry can be expected to produce less secondary employment than a development such as a coal-fired power plant. We did not develop a multiplier ourselves, but one study which evaluated the continuing development at The Geysers stated that 1.19 secondary jobs are generated for each job directly connected at the site.[1]

Finally, we recognize the ability to turn a mediocre employment picture into a highly optimistic outlook by the application of a simple multiplier. Therefore, we urge the reader to study the construction of the base to which the multiplier in this study has been applied.

---

[1] California Energy Resources Conservation and Development Commission, Consultant Report, p. V-C-1.

Supply Considerations

Established channels of manpower supply are still nonexistent in certain parts of the geothermal industry, especially where formal training programs are concerned. The geothermal industry must compete in the national market for scientific and engineering expertise. But university training for geothermal related areas is limited to a few classes at a small number of universities and to specific training for graduate students on research projects.

The supply of drilling personnel is best understood by viewing the drilling activity as an industry in itself. The problems are associated with a high turnover rate rather than initial recruitment, and the basic causal factor is the undesirable nature of the job. The problem is expecially acute where geothermal drilling occurs in areas where there has been no oil and gas well drilling actively. In the past the crucial supply consideration has been the availability of rigs rather than labor. Although this was not a main thrust of our investigation, we found little evidence to support the contention of a widespread shortage of rigs.

The supply of skilled construction personnel appears to be handled through union hiring halls and the unskilled labor is supplied from the populus surrounding the development area. Skilled operation and maintenance personnel are basically the result of internal promotion and training. At this point it does not appear that geothermal power plant operators have shown a proclivity to pirate skilled labor from other firms. Remote locations and slow growth have thus far precluded this type of action and provided ample time for planning manpower needs and assuring adequate supply.

Finally, a more detailed discussion concerning supply of particular occupations can be found in the technology assessment and personal interview summary.

Comparison of Forecasted Geothermal Employment with Other Energy Related Industries

In order to gain some perspective on the forecasted geothermal employment, comparisons with a few other industries will be made.[1] The Bureau of Labor Statistics has projected employment in a base case and in a high employment alternative case for 1985 and 1990. This facilitates easy comparison with our minimum and maximum estimates, and these are given as Table IV-2 on the following page.

Although the B.L.S. projections do not include the newer alternative energy industries, some investigators have made the following observation. "Although the subject of great interest and publicity, the 'emerging technologies' -- solar, geothermal, fusion, and bioconversion -- will not be large sources of new jobs over the next 8 to 10 years."[2]

It is important to keep in mind that our forecasted employment for the geothermal industry is founded in the achievement of projected output (power-on-line) as described by the IGCC's scenario. Also, our technique of forecasting a range of employment for a given year is based on minimum and maximum labor requirements to achieve a given task or complete a particular activity (e.g., well drilling) -- not on alternative output scenarios.

[1] Information about other industries was taken from Valerie A. Personik, "Industry Output and Employment: BLS Projections to 1990", *Monthly Labor Review*, 102 (April 1979): 3-14, especially pages 8-9.

[2] Willis J. Nordlund and John Mumford, "Estimating Employment Potential in U.S. Energy Industries", *Monthly Labor Review* (101) (May 1978): p. 10.

IV-1

Table IV-2

Comparison of Forecasted Employment in Energy Related Industries[1]

	Minimum		Maximum	
	1985	1990	1985	1990
Geothermal	11,802	37,073	32,339	101,482
	Base Case		**High Employment Alternatives**	
	1985	1990	1985	1990
Coal Mining	43,000	86,000	49,000	101,000
Crude Petroleum and Natural Gas	-14,000	-38,000	-11,000	-33,000
Oil and Gas Well Drilling & Exploration	22,000	45,000	29,000	44,000
New Public Utility Construction	83,000	170,000	101,000	214,000
Petroleum Refining & Related Products	-6,000	-10,000	-4,000	-7,000
Electric Utilities	68,000	75,000	82,000	104,000
Gas Utilities	-10,000	-41,000	-8,000	-32,000

[1] We have computed the employment figures to show the net gain in the 1980-1985 period in each industry in order that they might be more compatible with our estimate.

Forecast of Employment by Occupation

The forecast of employment growth by specific occupations stands upon much weaker logical and practical foundations than other parts of this study. The critical explicit assumption is that the occupational structure will not change during the forecasting period. Then the fixed coefficient technique is used with the additional assumption that employment has a direct (in this case, linear) relationship with output. However, the use of this technique allows two other related assumptions to creep into the model, and these must be made explicit in order to understand the weakness of this approach. The first is that we are actually assuming a zero elasticity of substitution between different kinds of labor (as defined via occupational titles). Second, the function of relative wages in the labor market has been omitted.

In addition to the general shortcomings outlined above there are specific problems associated with our effort. First, in order to develop a complete occupational profile of the industry we had to rely on two different sources. One is the Project Independence list of occupations and the other is the occupational profiles developed from the personal interview phase of our study. As previously stated, we believe the Project Independence list to be the most comprehensive available. However, it is based on a hypothetical industry structure much different than that developed in our forecasting model. Therefore, the absolute and relative quantities of individuals required in each occupation are highly questionable for our purposes.

On the other hand the occupational profiles developed from the personal interviews are based on an observation of particular firms engaged in different activities at a given point in time. This contrasts to the

Project Independence profiles which were constructed on the basis of need to complete a hypothetical plant in the future. One problem is that our occupational profiles are only piecemeal and therefore can not by themselves be used to make forecasts.

For example, the Project Independence occupational profile for resource exploration and appraisal lists that three geologists are required in this activity (leading to the construction of a 200 MW_e dry steam plant). In the personal interviews we had seven firms responding that they employed a total of 29 geologists for this purpose. Therefore, the two numbers (3 + 29) were added to obtain a total of 32. This is the number that appears for geologists in this activity in the occupational list and forecast in Appendix IV-B. This process was performed for each common occupation from the two sources and when occupations were only listed from one source, the accompanying number was used. Also, efforts were made to combine some occupations under a single heading (e.g., Administrative Management/Clerical), and to combine some different occupational titles under one term when it appeared there was no significant difference in job content (e.g., assistant driller and derrickman). The Dictionary of Occupational Titles (1977 Edition) was used in this effort.

The end result of the process outlined above was that each occupation has a total number of individuals, which when divided by the total number of individuals in the complete industry occupational structure, yields a proportion which can be used as a forecasting coefficient given the above assumptions. This coefficient is then multiplied by the forecasted minimum and maximum net gain in the total employment figures for 1980-1985, 1986-1990, and 1980-1990. This method, therefore, yields the requirements (in the number of individuals) for each occupation for these different categories.

This forecasting approach is admittedly highly arbitrary and subject to challenges on many practical and theoretical grounds. However, there is no alternative approach available. The defense lies in whether the resultant projections are more useful than none. If so, criticisms should be directed at refining this technique or developing a better one which will yield more dependable forecasts and will more accurately reflect the unique characteristics of the geothermal resource. Finally, a liberal interpretation (based on understanding the technique used) of the actual numbers generated by the model is urged. The reader should be aware that the literature on the subject of forecasting makes it clear that even highly accurate forecasts may lead to the wrong policy choice because of a failure to understand the construction of the forecasting model.

Having exposed the most important pitfalls of our model and its results, some more positive features will be discussed. First, we believe that a more complete and timely occupational structure of the industry has been developed. In several areas the occupational profiles from the personal interviews revealed new occupations that were not listed in the Project Independence list -- e.g., land managers, environmental engineers and technicians, and area planners. Also, by adding the quantity of individuals in common occupations from the two sources we believe that the occupations which have grown the most since 1974 have received the additional relative weights in calculating their coefficients. Inspection of Appendix IV-B reveals that many of the occupations that were described as bottleneck occupations in the personal interviews represent a considerable proportion of the industry, especially scientists and engineers. Based on our forecasting method, this also means their relative growth requirements will also be high and scarcity of these types of expertise may be more of a problem in the future.

IV 22

Appendix IV-A

The following four pages are abstracted from the Department of Energy - Interagency Geothermal Coordinating Council's Third Annual Report: Geothermal Energy, Research, Development & Demonstration Program (March 1979). Our report uses this scenario beginning with 1983. Data used for previous years - 1978 (608 MW_e), 1979 (908 MW_e), 1980 (971 MW_e), and 1981 (1301 MW_e) -- are from other sources and are cited in the text.

TABLE ES-1

POSTULATED GEOTHERMAL ELECTRIC POWER ON LINE, BY REGIONS, 1983-1990*
Cumulative Commercial-Scale Generating Capacity (MWe)**

	Pre-1983	1983	1984	1985	1986	1987	1988	1989	1990
REGION I (California, Hawaii, Alaska, Oregon, Washington)	1,680	1,990	2,210	2,790	3,065	3,690	4,390	4,940	5,940
REGION II (Arizona, Colorado, Idaho, Montana, Nevada, New Mexico, Utah, Wyoming)	--	200	200	300	600	800	1,300	1,350	2,350
REGION III (Louisiana, Texas)	--	--	--	--	25	325	425	525	1,025
U.S. Total***	1,680	2,190	2,410	3,090	3,690	4,815	6,115	6,815	9,315

*The postulated generating capacities are based on current knowledge of the geothermal resources in the Regions. Figures are intended for planning purposes only and do not imply any commitment on the part of the Federal government to develop these sites.

**Pilot plants and test facilities have not been included in these totals.

***Region IV, the Eastern States, has not been included in this table because the Region's geothermal resources are postulated to undergo only direct thermal utilization.

Table 6

GEOTHERMAL ELECTRIC SCENARIOS POSTULATED BY THE IGCC
FOR PLANNING PURPOSES* -- REGION I

Generating Capacity Installed Each Year (MWe)

	Pre-1983	1983	1984	1985	1986	1987	1988	1989	1990	1990-2020	Total
Alvord, OR	--	--	--	--	--	50	--	--	50	200	300
Baker Hot Springs, WA	--	--	--	--	--	--	--	--	50	--	50
Brawley, CA**	--	50	--	50		100	100	100	100	500	1,000
Coso Hot Springs, CA	--	--	--	50	50	50	150	150	150	--	600
East Mesa, CA**	--	--	--	50	--	--	50	--	--	--	100
Geysers, CA (hot water)	--	--	--	100	100	100	100	100	100	400	1,000
Geysers, CA (steam)	1,680	160	220	110	--	--	--	--	--	--	2,170
Glass Mt., CA	--	--	--	--	--	--	--	--	50	--	50
Heber, CA	--	50	--	50	--	100	100	--	--	700	1,000
Lassen, CA	--	--	--	--	--	50	--	--	50	--	100
Mono-Long Valley, CA	--	--	--	50	--	100	--	--	100	--	250
Mount Hood, OR	--	--	--	--	--	--	--	--	50	--	50
Puna, HI	--	--	--	20	--	--	--	--	50	850	920
Salton Sea, CA	--	50	--	100	75	75	100	100	100	1,400	2,000
Surprise Valley, CA	--	--	--	--	50	--	50	100	100	1,700	2,000
Vale Hot Springs, OR	--	--	--	--	--	--	50	--	50	700	800
Total Installed Power On Line	1,680	1,990	2,210	2,790	3,065	3,690	4,390	4,940	5,940	12,390	12,390

*The selection of sites and the postulated generating capacities are based on current knowledge of the geothermal resources in the region. The scenario is intended for planning purposes only and does not imply any commitment on the part of the Federal government to development at these sites. Generating capacity estimates in Table 1 (p. 14) for the years after 1985 assume development of additional sites.

**The IGCC postulates that a 10 MWe pilot plant will be completed at East Mesa in 1978 and at Brawley in 1979.

Table 8

GEOTHERMAL ELECTRIC SCENARIOS POSTULATED BY THE IGCC
FOR PLANNING PURPOSES* -- REGION II

Generating Capacity Installed Each Year (MWe)

	Pre-1983	1983	1984	1985	1986	1987	1988	1989	1990	1990-2020	Total
Brady Hot Springs, NV	--	50	--	--	50	--	100	--	100	700	1,000
Beowawe, NV	--	50	--	--	50	--	50	--	100	750	1,000
Bruneau-Grandview, ID	--	--	--	--	--	50	--	--	100	3,000	3,150
Chandler, AZ	--	--	--	--	50	--	--	--	100	80	230
Cove Fort-Sulphurdale, UT	--	--	--	50	--	50	--	50	50	1,300	1,500
Leach, NV	--	--	--	--	--	50	--	--	50	1,400	1,500
Raft River ID	--	--	--	--	--	--	50	--	50	700	800
Roosevelt Hot Springs, UT	--	50	--	--	50	--	50	--	100	750	1,000
Safford, AZ	--	--	--	--	--	50	--	--	--	50	100
Steamboat Springs, NV	--	--	--	50		--	50	--	100	--	200
Thermo, UT	--	--	--	--	--	--	50	--	--	450	500
Valles Caldera, NM	--	50	--	--	100	--	100	--	100	1,150	1,500
Weiser-Crane Creek, ID	--	--	--	--	--	--	50	--	100	850	1,000
West Yellowstone, MT	--	--	--	--	--	--	--	--	50	--	50
Total Installed Power On Line	0	200	200	300	600	800	1,300	1,350	2,350	13,530	13,530

*The selection of sites and the postulated generating capacities are based on current knowledge of the geothermal resources in the region. The scenario is intended for planning purposes only and does not imply any commitment on the part of the Federal government to development at these sites. Generating capacity estimates in Table 1 (p. 14) for the years after 1985 assume development of additional sites.

TABLE 10
GEOTHERMAL ELECTRIC SCENARIOS POSTULATED BY THE IGCC
FOR PLANNING PURPOSES* -- REGION III

Generating Capacity Installed Each Year (MW_e)

	Pre-1983	1983	1984	1985	1986	1987	1988	1989	1990	1990-2020	Total
Acadia Parish, LA	--	--	--	--	--	50	--	--	50	250	350
Brazoria, TX	--	--	--	--	25	--	100	100	200	1800	2225
Calcasieu Parish, LA	--	--	--	--	--	50	--	--	50	250	350
Cameron Parish, LA	--	--	--	--	--	50	--	--	50	400	500
Corpus Christi, TX	--	--	--	--	--	50	--	--	50	1550	1650
Kenedy County, TX	--	--	--	--	--	50	--	--	50	200	300
Matagorda County, TX	--	--	--	--	--	50	--	--	50	400	500
Cumulative Total					25	325	425	525	1025	5875	

*The selection of sites and the postulated generating capacities are based on current knowledge of the geothermal resources in the region. The scenario is intended for planning purposes only and does not imply any commitment on the part of the Federal government to development at these sites. The generating capacity estimates in Table 1 (page 14) for the years after 1985 assume development of additional sites.

Appendix IV-B

In order to derive the forecasting coefficient each number under the category entitled "Summed Total of Individuals from Surveyed Firms and Project Independence" was divided by 885 -- the total of all individuals in all occupations. Note that 885 is not to be construed as total employment in this segment of the industry (See the text for more explanation on this point). It is merely a base from which the relative employment (forecasting coefficient) in each occupation can be derived.

AN ASSESSMENT OF EXPECTED TECHNOLOGY DEVELOPMENTS IN THE GEOTHERMAL INDUSTRY

Introduction

The necessity for a technology assessment of the geothermal industry is founded on two basic factors. The first concerns the heterogeneous nature of the energy resource on which the industry is based. For example, the technology necessary to develop and utilize hot water, hot rock, or geopressured geothermal energy is significantly different from the technology for dry steam. Economic development of geothermal resources other than dry steam will require technological modifications or the introduction of new technology, assuming a favorable relationship with the prices of alternative energy resources.

The second factor creating the necessity for a technology assessment is that it will help in understanding the technical obstacles which must be overcome in order for industry growth to proceed at its anticipated rate. Technological changes that support and enhance this growth will in some degree alter the quantity and quality of manpower demanded by the industry vis-a-vis productivity change. In making manpower projections it is prudent to take into account the impact of technology, at least in a qualitative sense.

A by-product emerging in this part of the study that is related to current manpower assessment is the perception of whether or not scientific, engineering, and technical personnel exist in adequate quantity and quality to carry technology forward at its anticipated pace. This is not an area of investigation to be taken lightly. For example, one study has pointed out that insufficient funds or manpower is at least a "marginally significant" factor when considered as a barrier to technological innovation -- ranking above insufficient funds for new facilities and unavailability of capital.[1] The importance of research and development manpower receives even greater emphasis from a different report.

> It may be concluded that competent people are the major resource for innovation. A primary responsibility of management is then the selection, development, retention, and effective utilization of technical personnel, including the facilitation of personal contacts both inside and outside the organization.[2]

General Method of Approach

The first step was to conduct a literature search in order to determine the extent to which the subject of technology assessment in the geothermal industry has been treated. Even though geothermal may be characterized as a relatively new or "infant" industry, there have been in recent years a number of publications dealing exclusively or in part with geothermal technology.[3] In addition the subject is continuously explored in numerous journals.[4]

---

[1] Barriers to Innovation in Industry: Opportunities for Public Policy Changes, Prepared for the National Science Foundation by Arthur D. Little, Inc. and Industrial Research Institutes, Inc., September 1973, p. 19. Note that this example was not a unique characteristic of any specific industry but was a widely perceived phenomenon.

[2] Successful Industrial Innovations: A Study of Factors Underlying Innovation in Selected Firms, National Science Foundation, 1970, p. 62.

[3] For example, see, Second U.N. Symposium on the Development and Use of Geothermal Resources, 3 Vols., San Francisco, 1975; A Technology Assessment of Geothermal Energy Resource Development, Prepared for the National Science Foundation by the Futures Group (April 15, 1975); Geothermal: State of the Art: Papers Presented at the Geothermal Resources Council Annual Meeting, 9-11 May 1977, San Diego, California; and Paul N. Cheremisinoff and Angelo C. Morresi, Geothermal Energy Technology Assessment (Westport, Conn.: Technomic Publishing Co., Inc., 1976).

[4] For example, Machine Design, Geothermal Energy Magazine, Chemical Engineering Progress, and Society of Patroleum Engineers Journal.

The literature search served dual purposes. First, it helped identify the particular technology developments necessary for projected industry growth, and second, it established the footing on which the Delphi method (explained below) was based.

A valid question that arises is directed at determining why still another effort should be made at assessing geothermal technology. The answer is in two parts. First, the other studies were basically geared toward assessing the impact of novel technology on industry growth and were not directly concerned with the ultimate results in terms of employment or occupational structure. Second, the validity and timing of many research forecasts changed drastically with the passage of time, influence of government policy, and the generally downward revisions of how significant a contribution geothermal energy can make on the national and local levels.

By comparison the technology assessment study undertaken by the Human Resources Institute is modest in scope and uses a more limited horizon (1985). Though the input for making manpower projections provided by this part of the study is still of a qualitative nature, it is hoped that this comparatively narrow approach is both more realistic and more precise in its results. Finally, more confidence is lent because the relatively near time horizon precludes much pure speculation about as yet undefined and futuristic technological products, components, or processes. However, given the Department of Energy-Division of Geothermal Energy (D.O.E.- D.G.E.) scenario for geothermal development, there is a continuing need to evaluate the probability that the necessary technology developments will take place which are critical to the attainment of forecasted industry growth on which manpower projections are dependent. One method of doing this is to poll the industry's technical experts and solicit their judgments relating to specific technological events. The specific approach used in this study to accomplish this purpose was the Delphi method.

Delphi Method

There are a number of variants of the Delphi technique which in some cases are tailored for the specific research purpose. However, it is essential to adhere to certain methodological basics. What follows is first, a general presentation of the method and second, an explanation of how the technique was applied to technology assessment in the geothermal industry.

Definition and Methodology of the Delphi Technique

The following two excerpts are general statements of what the Delphi technique is and the procedure for its utilization.

> The usual forecast attempts to predict what could be -- DELPHI tries to predict what will be. DELPHI could be described as an elegant method for developing a consensus. It is a polling technique employed for the systematic solicitation of expert opinion. DELPHI bears deeper investigation because it is directed toward the prediction of the future as it will develop in a situation influenced by many factors beyond the control of the company or agency making the forecast. Its methodology includes the polling of experts representing the controlling factors and from the ensuing data develops a consensus which can be used in planning. Its advantage consists in the systematic treatment of data that includes the experts' intuitive assessment of relative imponderables.[1]

---

[1] Marvin J. Cetron, Technological Forecasting, (New York: Technological Forecasting Institute, 1969), p. 145.

Delphi is a method of systematic interrogation of experts; the interrogation is conducted anonymously by formal questionnaires and for individual members of the group of experts; a central authority evaluates the answers and makes the answers available to those interrogated in a new round of questions; after several such rounds, the result generally is that highly deviating opinions increasingly adapt themselves to one another; the questions are concerned either with an estimate of a certain year of with an estimate of a probability value for the occurence of an event at a certain date; in the evaluation of the questions, the medians concerned and the average quartiles of the individual answers are calculated.[1]

A thorough explanation of the advantages and disadvantages of the Delphi method are extensively enumerated elsewhere and therefore do not warrant consumption of space in this text.[2] Instead, the problems of using the approach as directly related to this specific study will be pointed out in the next section. The usefulness of the technique has already been stated as being derived from its relatively simple approach to the problems of technology development.

Application of the Delphi Technique to the Geothermal Industry

The use of the Delphi technique in this study is intended:

(1) to enable some perception of

---

[1] K. Gewald, "The Delphi Method as an Instrument of Technological Forecasting -- Practical Experience," in Technological Forecasting in Practice, eds. Hans Blohm and Karl Steinbuch, trans. Frederick and Christine Crowley (Lexington, Mass.: Lexington Books, 1972), p. 14.

[2] See Gewald, pp. 14-16, Cetron, pp. 158-159, and Larry Evans, Production Technology Advancements: A Forecast to 1988, (Ann Arbor, Michigan: Industrial Development Division, Institute of Science and Technology, University of Michigan, 1973), pp. 37-42, and Robert U. Ayres, Technological Forecasting and Long-Range Planning, (New York: McGraw-Hill Book Co., 1969), pp. 148-150.

technological breakthroughs which are likely to occur by 1985 and the potential for existing or expected technology to become commercially feasible by that date; and (2) to use this information as input in forecasting manpower requirements. Because of the heavy time and resources involvement required in a Delphi study only two formal rounds of questioning were concluded. The results appear to indicate that this was sufficient for the above mentioned purposes.

In a sense the earlier explanation of the general approach of the Delphi method might be considered idealistic because in order to gain maximum use from the technique one must modify it to the particular investigation being conducted. However, certain methodological procedures must be kept as pure as possible -- e.g., the selection of experts and anonymity.

The basic method of selecting experts to be surveyed was to identify individuals who had published works concerning the technology of the industry. The polling of these experts then depended on obtaining their addresses through such sources as the Geothermal Resources Council or Geothermal World Directory.

The above procedure was subject to two qualifications. First, in order to avoid making unreasonable requests, an effort was made to eliminate the possibility of including the same persons in the Delphi study who were on the mailing list for Phase I. Some exceptions were unavoidable since in many cases the Phase I survey was only addressed to a firm, and the individual respondent was not identified until the questionnaire was returned. Also, a few experts were knowingly polled in both studies because of their recognition as key figures in the industry. This factor does not appear to have produced negative responses.

The second qualification is that care was taken to ensure that experts selected were representative of the different segments of the industry. The criterion used was the attempt to generally balance the numbers included in the categories of resource exploration and appraisal, reservoir development, and energy conversion. The environmental aspects of the industry appear to have commanded relatively less attention in the literature; therefore, a smaller number of experts were identified and surveyed in this category.

The total number of experts surveyed in the first round was 103.[1] The second-round mail survey was determined from the following tabulations.[2]

103	total in first-round survey
-57	nonrespondents and unuseable responses
46	useable responses
- 8	declining further participation
38	potential second-round participants
- 8	further participation only by telephone or personal interview
30	total second round mail survey
- 8	nonrespondents to second-round survey
22	responses to second-round survey

---

[1] As a first impression one might consider this number or the 30 included in the second-round mail survey to be inadequate for a valid sampling of different opinions. However, these numbers appear to be quite consistent by comparison with other Delphi studies, especially considering our more modest objectives. For example, see Irene Anne Gillson, "The National Drug-Abuse Policy Delphi: Progess Report and Findings to Date," and Selwyn Enzer, "Plastics and Competing Materials by 1985: A Delphi Forecasing Study," in The Delphi Method: Techniques and Applications, eds. Harold A. Linstone and Murray Turoff, (Reading, Mass.: Addison-Wesley Publishing Company, 1975).

[2] Full documentation of correspondence and the questionnaires used can be found in the appendix.

After concluding the first-round survey, the next step was to edit the responses in order to develop a concise set of controlling technological factors to be evaluated by participants in the second round. This was a point of considerable difficulty in this study because of the technical language used by some respondents and the "non-expert" status of the controlling authority. Fortunately, there is considerable literature available of an explanatory and/or definitional nature that greatly reduces this problem. The bibliography in the appendix represents most of the published materials consulted for this purpose. Also, communications with several individuals active in the industry helped clarify many terms. However, some ambiguities did remain in the list of controlling factors, and these will be pointed out in the presentation of the statistical results. It should also be noted that the list of controlling factors used in the second round is by no means all-inclusive. Our effort was directed only at the factors given by the participants and no additional factors were added to the list.

A less serious problem was created by asking the respondents to indicate their area of expertise. There were a large number of multiple responses, but there were also a signficant number of responses to "other". However, these did tend to fit logically into one of the four major areas, thus indicating that some major category of experts had not been omitted from the survey. The classification of first and second-round respondents by areas of expertise is given on pages 10 and 11.

Statistical Results

Pages 12 - 14 give the distribution of the responses of the 22 respondents to the second-round of the survey. The distribution is given by percentage of responses in each category. Horizontal summations may not equal 100 percent because of nonresponse to particular factors. However, this result may be considered as a technical error in the survey design since nonresponse and "no judgment" may be subsumed under one category.

The relatively large percentages expressed in the "No Judgement" category primarily result from the selection of experts in different fields of specialization. There is general consistency in that experts predominantly responded to the areas within their individually designated specialization(s) and responded less to other areas of expertise.

A few resondents pointed out the ambiguous nature of three of the factors listed in the survey. Two were "plugging reinjection wells" and "carbon steels". In the case of the former the factor <u>is</u> the problem and thus should have been phrased within this context in order to determine if there will be a significant contribution toward the solution of the problem. For the latter factor the criticism was that it is the development of new alloys that is critical and that carbon steels are currently available. The third factor that appeared ambiguous to respondents was the capability of drilling "wells deeper than 12-15,000 feet." Since some considered this capability to already exist, the question arose if there could continue to be a significant contribution.

A few participants observed that there was a lack of specific references to direct use technology. However, given this shortcoming and those mentioned above, the rest of the feedback was that the list of controlling factors was comprehensive.

CLASSIFICATION OF FIRST ROUND RESPONDENTS BY AREAS OF EXPERTISE

Identification Number	Resource Exploration And Appraisal	Reservoir Development	Energy Conversion	Environmental	Other
1			X		X
2			X		
3			X		
4			X		
5			X		
6			X		
7			X		
8			X		
9			X	X	X
10	X		X		
11			X	X	
12			X	X	X
13	X	X			
14	X	X	X	X	
15	X				
16	X				
17	X				
18	X				
19	X				
20	X	X			
21	X				
22	X	X			
23	X	X			
24	X				
25	X				
26	X	X		X	
27	X				
28		X			X
29		X			
30		X			X
31		X			
32		X		X	
33		X		X	
34				X	
35		X	X	X	
36	X	X			
37		X			X
38		X			
39			X		
40					X
41			X		
42	X		X	X	
43		X		X	
44		X			
45		X			
46			X		
TOTAL	18	20	17	11	7

CLASSIFICATION OF SECOND ROUND RESPONDENTS BY AREAS OF EXPERTISE

Identification Number	Resource Exploration And Appraisal	Reservoir Development	Energy Conversion	Environmental	Other
1		X			
2			X		X
3			X		
4			X		
5			X		
6			X		
7			X		
8	X	X	X	X	
9	X				
10	X	X			
11	X	X			
12	X				
13	X				
14		X			X
15		X			
16		X			
17		X		X	
18		X			X
19		X			
20		X			
21	X		X	X	
22					
TOTAL	7	11	8	3	3

II-72

GEOTHERMAL MANPOWER PROJECT/HUMAN RESOURCES INSTITUTE/UNIVERSITY OF UTAH
Delphi Survey of Technology Developments in the Geothermal Industry/Second Round

Would you like a copy of the final results of this study? ___ Yes ___ No
(Please Check)

	Likelihood of significant contribution by 1985				Present sophistication does not require further technological development	No Judgment
	0-25%	26-50%	51-75%	76-100%		
I. Resource Exploration/Appraisal						
Remote sensing						
Satellite imagery	40.9%	0%	4.5%	4.5%	9.1%	40.9%
High altitude aerial photography	40.9	0	4.5	4.5	13.6	36.4
Surface surveys						
Magnetotelluric	9.1	4.5	36.4	4.5	9.1	36.4
Microearthquake	22.7	9.1	22.7	.0	9.1	36.4
Resistivity	13.6	13.6	18.2	4.5	13.6	31.8
Subsurface surveys						
Key element logging during drilling	9.1	27.3	13.6	18.2	.0	31.8
Gasses survey as an exploratory tool	13.6	31.8	18.2	4.5	.0	27.3
Development of well logging tools with multiple capabilities that can operate under high temperatures (250°C-350°C) and under adverse chemical conditions	4.5	18.2	22.7	27.3	.0	27.3
Integrated thermionic circuits (up to 600°C)	9.1	22.7	18.2	.0	.0	50.0
Reservoir simulation						
Computer modeling	22.7	18.2	9.1	18.2	4.5	27.3
Physical modeling	22.7	18.2	18.2	9.1	.0	31.8
II. Drilling Technology Advances						
General advanced capabilities						
Wells deeper than 12-15,000 feet	18.2	13.6	13.6	4.5	13.6	36.4
Multiple legs for bottom hole	4.5	13.6	4.5	18.2	18.2	36.4
Directional drilling capabilities	9.1	9.1	4.5	18.2	22.7	27.3
Specific developments						
Improved drilling motors	18.2	9.1	.0	13.6	4.5	45.5
Improved drill bits	4.5	22.7	13.6	18.2	.0	40.9
Downhole replacable drill bits	13.6	22.7	4.5	13.6	.0	45.5
Improved coring tools	13.6	13.6	9.1	18.2	.0	40.9
Advances in high temperature casing	13.6	18.2	9.1	9.1	4.5	40.9
Improved methods of seating and sealing of casing	.0	18.2	18.2	22.7	.0	36.4
Drilling of large diameter wells for hot water systems	4.5	9.1	13.6	9.1	13.6	50.0
Use of foams for drilling fluids	.0	22.7	9.1	9.1	.0	54.5
III. Reservoir Development						
Prediction						
Prediction of where scaling will occur in the reservoir/energy conversion system	.0	13.6	40.9	22.7	.0	18.2
Prediction of subsidence	9.1	59.1	9.1	.0	.0	22.7
Reinjection						
Improvement or reinjection techniques	4.5	18.2	22.7	31.8	.0	18.2
Plugging reinjection wells	9.1	27.3	18.2	18.2	.0	27.3

(Please Check)

	Likelihood of significant contribution by 1985 0-25%	26-50%	51-75%	76-100%	Present sophistication does not require further technological development	No Judgment
III. Cont.						
Materials						
High temperature open hole packers for formation fracturing & stimulation	9.1	13.6	9.1	18.2	.0	50.0
Improvements in down hole pumps	4.5	9.1	27.3	31.8	.0	27.3
Cements	4.5	18.2	22.7	13.6	.0	36.4
High temperature elastomers	13.6	4.5	18.2	13.6	.0	45.5
High temperature explosives	4.5	18.2	13.6	4.5	.0	59.1
Stimulation						
Mechanical fracturing	18.2	18.2	.0	4.5	.0	54.5
Explosive fracturing	4.5	22.7	18.2	9.1	.0	40.9
Hydraulic fracturing	9.1	13.6	18.2	9.1	.0	50.0
Well stimulation with secondary fluid	9.1	13.6	9.1	9.1	.0	54.5
Scaling and corrosion						
Extraction of useful materials from geothermal brines	9.1	18.2	31.8	13.6	4.5	22.7
Removal of noncondensibiles directly from steam	18.2	22.7	13.6	.0	.0	45.5
In-situ acidification of high salinity fluids for scale control & removal of mineral constituents	9.1	31.8	13.6	.0	4.5	36.4
Silica removal from hypersaline brine	22.7	31.8	13.6	9.1	.0	22.7
Future development of reservoir systems						
Hot dry rock energy extraction loops	36.4	27.3	9.1	9.1	.0	18.2
Geopressured systems for thermal energy, hydraulic energy, and/or natural gas	18.2	18.2	27.3	13.6	.0	22.7
Volcanic heat sources	45.5	9.1	13.6	9.1	.0	22.7
IV. Energy Conversion						
Materials						
Carbon steels	18.2	18.2	4.5	9.1	9.1	31.8
Titanium alloys	18.2	9.1	4.5	9.1	18.2	36.4
Specific technology						
Large radial inflow turbines capable of isolating brines from the turbine area	27.3	22.7	4.5	4.5	.0	31.8
Pumps, valves, & instrumentation which will operate in a scaling environment	.0	31.8	18.2	18.2	.0	27.3
Heat exchanger automatic descaling	13.6	36.4	13.6	.0	.0	31.8
Heat exchangers for less than 150°C use	22.7	18.2	.0	18.2	4.5	31.8
Down hole heat exchanger	18.2	27.3	13.6	4.5	.0	31.8
Direct contact condensers	9.1	27.3	4.5	9.1	9.1	31.8
Well head generator (screw expander)	9.1	13.6	18.2	13.6	.0	40.9
Turbines for less than 150°C use	31.8	18.2	9.1	9.1	4.5	22.7
Total flow turbines	22.7	18.2	22.7	9.1	.0	22.7
Flash vaporizers for pure water conversion	18.2	18.2	13.6	9.1	.0	36.4
Systems technology						
Use of multiple stage flashing systems	9.1	13.6	22.7	27.3	4.5	22.7
Direct flash of high salinity geothermal fluids	18.2	18.2	13.6	22.7	.0	18.2
Binary power cycles (with separated working fluid)	4.5	31.8	22.7	13.6	4.5	18.2

IV 14

(Please Check)

	Likelihood of significant contribution by 1985				Present sophistication does not require further technological development	No judgment
	0-25%	26-50%	51-75%	76-100%		
IV. Cont.						
Direct contact binary cycle	22.7	27.3	27.3	.0	.0	18.2
Total flow utilization systems	4.5	54.5	4.5	13.6	.0	22.7
Hybrid power plants	4.5	27.3	22.7	9.1	.0	27.3
Cascaded energy systems	.0	18.2	27.3	13.6	.0	36.4
V. Environmental						
Improved economic disposal of power plant effluents--e.g., brine reinjection, sludge, gases	4.5	31.8	13.6	31.8	.0	9.1
H_2S abatement	9.1	45.5	13.6	18.2	4.5	9.1
Noise abatement	18.2	22.7	18.2	27.3	.0	13.6
Subsidence abatement	22.7	31.8	18.2	4.5	4.5	18.2
Water pollution abatement	13.6	40.9	4.5	27.3	4.5	9.1
VI. Other (please identify)						

VII. Comments

As is obvious from the examination of the data by specific controlling factors, in several cases the distribution of responses do not allow conclusive results. However, some general observations can be made. Before doing so we would like to point out that in retrospect much of the real contribution of this technology survey is to be found in reading the responses to the questions to round one, which are given in detail in the appendix. Perhaps even more interesting are the additional comments that were invited and received in rounds one and two, and in the subsequent mailing of preliminary results to participants -- also edited and reprinted in the appendix. The reader is urged to read these comments for some enlightened insight into not only technological but also institutional problems of the geothermal industry.

In round two the edited list of controlling factors was sent to the 30 participants who had agreed to further questioning. Of these 30, 22 usable responses were received.[1] The following question and explanation were given in the cover letter.

> Given your area of specialization, with what probability do you expect advancing technology to enable the factors listed to make a significant contribution to the geothermal industry by 1985?
>
> Significant contribution cannot be precisely defined or quantified, but any technical development which (a) removes a serious technical impediment to the development of geothermal energy resources, (b) contributes substantially to the solution of unresolved problems in the production, development or practical use of geothermal energy, or (c) contributes directly and substantially to an increase in the

---

[1]One participant responded that he did not wish to reply to the questions. Two others had moved and left no forwarding address. The remaining five failed to respond to follow-up letters and received no additional communications.

production and practical application of geothermal energy can be considered to be making a significant contribution.

Referring to the results of pages 12 - 14 we first examine Category I, Resource Exploration and Appraisal. The general tendency here is that it is not expected that remote sensing technology -- satellite imagery and high altitude aerial photography -- will make a significant contribution in appraising the inventory of geothermal resources. It appears that relatively more confidence is placed in reservoir simulation modeling; however, it should be noted that a plurality of those addressing this factor still assigned a 0-25% probability of a significant contribution. In contrast, most of the replies to the surface and subsurface techniques fell within the middle two quartiles. This appears to reinforce the view that these techniques will continue to dominate geothermal resource exploration and appraisal. The implication is that these techniques require intensive on-site use of men and equipment relative to remote sensing and reservoir simulation.

Category II, Drilling Technology Advances, reveals that the factors under general advanced capabilities will not prove a serious limitation.[1] This in part may be a reflection of technological developments that are transferred from the oil and gas industries into the geothermal industry. However, the factors that were listed as specific needs (as given in the round-one questionnaire responses) for enhancing geothermal development

---

[1] This interpretation is in part based on the high proportional response in the "Present sophistication does not require further technological development" category. Also, note the earlier restriction placed on the deep well factor -- see page 9.

were viewed with more uncertainty. Drilling technology is a crucial area of geothermal development because of the adverse conditions (high temperatures, corrosive fluids, highly abrasive rock formations, etc.) under which drilling must take place. This problem is being approached by intensive research and development efforts.[1]

Category III, Reservoir Development, revealed a relatively high degree of confidence in predicting the occurence of scaling but considerably less confidence in the prediction of subsidence. This latter result is generally consistent with the replies to the environmental (Category V) factor of "subsidence abatement." Some respondents (and others not in this study) expressed concern that the solution to such environmental problems may pose considerable obstacles in the future.

Also in reservoir development it appears that improvements in downhole pumps are a distinct possibility. In contrast, "silica removal from hyper-saline brine" was not viewed favorably. This may prove to be a serious limitation for development sites that are based on hot water. It is interesting to note that under the more futuristic types of reservoir systems -- hot dry rock, geopressured, and volcanic -- only geopressured received a relatively favorable response. As a final observation on reservoir development, note that this category was least likely to have factors that were viewed as not requiring further development.

Under Category IV, Energy Conversion, the subcategories of materials and specific technology yield mixed results with no apparent significant trend. Two marked observations are the large proportional responses

[1] At the time of this study Sandia Laboratories (Albuquerque, N.M.) was heavily engaged in these efforts.

in the 0-25% likelihood of contributions from "large radial inflow turbines" (27.3%) and "turbines for less than 150° C use" (31.8%). Under systems technology it seems that the leading contender is the multiple stage flashing system. However, with the exception of the "direct flash of high salinity geothermal fluids" all the other energy conversion systems received the largest proportion of responses in the middle two quartiles. Category V, Environmental, again yields mixed results with the largest proportion of responses being grouped in the middle 50%. To emphasize an earlier statement, many experts hold the view that environmental factors will play a larger role as the industry develops, especially with tighter regulatory controls.

A Qualification of the Statistical Results

A word of caution must be given concerning the compilation of the probability assignments. In aggregating the results, each reply was given equal weight for each of the controlling factors, regardless of the area of expertise of the participant. For example, an expert in resource exploration and assessment was given equal weight in his response to an energy conversion factor as was given to an expert in energy conversion. This undoubtedly biases the results somewhat. However, attempts to detect the degree of bias by comparing the "nonexpert" (relating to a given category) group response with the experts' response by category were not meaningful. Comparisons both by absolute numbers of responses and the percentage of responses for each group did yield a general consistency in the probability assignment categories (e.g., 0-25%, 26-50%, etc.). But given the small sample size for the second round (22), subdividing the respondents into several groups for comparison was not a useful analysis.

Comparison of Delphi Results with Other Geothermal Technology Literature

A considerable body of literature related to geothermal energy technology development has been published since 1970. There is little dissent from the view that if the industry is to continue to grow, readily available and economically feasible technology must be forthcoming in a large number of areas. This is especially true since the resource exists in many forms, and industry growth will depend on using the more marginal resource types. This view is perhaps more succinctly stated in a 1975 report by the Jet Propulsion Laboratory -- California Institute of Technology.

> Technology presently exists or is being developed which will allow the economic exploitation of vapor- and high-grade liquid dominated hydrothermal reservoirs. However, these are estimated to be only a fraction of the total geothermal energy available. *To sustain the growth rate of geothermal utilization throughout the remainder of the century, the technology for economic exploitation of other types of geothermal resources (hot dry rock, geopressured systems, normal gradient, and magma) must be developed.*[1]
>
> [Italics added]

Studies of geothermal technology have been both highly specific (e.g., pertaining to a single technical factor) and general (e.g.,

---

[1]Jet Propulsion Laboratory, California Institute of Technology, Program Definition for the Development of Geothermal Energy -- Volume I: Background and Program Definition Summary (Pasadena, California: 1975), p. 19.

surveying experts for opinions on a wide variety of issues). The results from this study will now be compared with opinions and conclusions from other publications. One of the more thorough investigations was conducted by the Bechtel Corporation and presented in a study prepared for the National Science Foundation in 1975.[1] Because the Bechtel format allows an easy and interesting comparison with our study, contrasts on several commonly surveyed factors will be presented. Additional information from other studies will also be presented within this context.

Resource Exploration and Appraisal

Our results reinforce the Bechtel results concerning the feasibility of improvements in remote sensing. Though the former study contains very little commentary on aerial surveys (except to imply that this method is considerably more refined than satellite imagery), it does state "The present thermal infrared scanning instruments appear to be ineffective for the purpose of conducting gross geothermal exploration."[2] The Bechtel study further concludes that even under a crash program, remote thermal infrared sensing capabilities could only be expected to increase 10-50 percent by the year 2000.

---

[1] The Futures Group, A Technology Assessment of Geothermal Energy Resource Development. Prepared for the National Science Foundation (Contract - C-836), (April 15, 1975). Note that the Bechtel portion of the study was actually conducted in late 1973. Also, the Bechtel initially solicited 31 prospective interviewees of which one declined at the outset and six others subsequently declined or failed to respond. See pages 101 and 102 for an explanation of the interview procedure. The technology analysis from the Bechtel study and referred to in this study can be found on pages 120-126 and 251-269 in the above reference.

[2] Ibid., p. 252.

In addition, the literature reveals that there does not appear to be a significant interest in remote sensing techniques.[1] These findings lead to the conclusion that there will not be significant contributions from this method of resource exploration and appraisal.

We will leave the treatment of surface and subsurface techniques for later and will now take up the category of reservoir simulation. The different types of modeling procedures, as was the case with remote sensing, have also not been rigorously investigated on a wide scale by technological experts, although our results were not as clear-cut as in the case of remote sensing.

The Bechtel study states that there is a "lack of coherent, verified, dynamic reservoir models [and] to date there are no simulation models available which allow accurate prediction of dynamic reservoir behavior."[2] The study goes on to say that this is not a critical path of development and that it should become more feasible as more drilling and other exploration data become available. However, as Bechtel pointed out and as our research continued to verify, there may be serious problems in collecting the necessary data in a centralized source for public use

---

[1] This is not only true of journal articles. The following documents give only passing reference or no reference to remote sensing techniques as an area to be singled out for further development: U.S. Department of Commerce, National Technical Information Service, An Assessment of New Options in Research and Development, November 1973; Federal Energy Administration, National Science Foundation, Project Independence: Geothermal Energy, November 1974; Ranvir K. Trehan, et.al., Analysis of Geothermal Energy Development Scenarios (Mitre Corp., Metrek Div.: November 1976); Energy Research and Development Administration, Geothermal Energy Research, Development and Demonstration Program, April 1977; and Department of Energy, Federal Interagency Geothermal Coordinating Council, Geothermal Energy, Research, Development and Demonstration Program, April 1978.

[2] The Futures Group, A Technology Assessment of Geothermal Energy Resource Development, p. 121.

because of its proprietary nature.[1]

Unlike the remote sensing category one can find considerable interest in reservoir modeling.[2] Perhaps the main reason for continued efforts in this area is given in the following quotation.

> One of the most significant limits on geothermal growth rate is the risk of pre-mature reservoir failure. Although the investment indemnity program can shift the risk from industry to the government, the only way this risk can really be reduced is by developing reliable reservoir modeling techniques . . . Reliable reservoir analysis techniques directly affect the development of geothermal fields. They are in part responsible for the faster development time for The Geysers, 20 years, as compared to the 75-year development time at Larderello, Italy. Without government programs, 50 MW_e will probably be a typical incremental addition to any geothermal field and may result in slow growth rates for geothermal exploitation. With reliable modeling techniques, growth increments might be increased to 100MW_e or more and the decision time to commit to new development could be decreased by more than 50%.[3]

Despite continuing efforts at geothermal reservoir modeling there do not appear to have been major breakthroughs, at least on the level of significance that would put this method of geothermal resource assessment on par with that of the oil and gas industries. Our statistical results support the view that significant progress is not likely before 1985.

---

[1] The U.S.G.S. has developed the Geotherm data file which contains data on the physical characteristics, geology, geochemistry, and hydrology of geothermal resources.

[2] For examples, see papers reprinted in the Geothermal Resource Council's Geothermal: State of the Art (May 1977) and Geothermal Energy: A Novelty Becomes a Resource (July 1978). Other discussions can be found in Arthur L. Austin, et.al., Lawrence Livermore Laboratory, The LLL Geothermal Energy Program Status Report January 1976-January 1977, pp. 131-148; Energy Research and Development Administration, Geothermal Energy Research, Development, and Demonstration Program (April 1977), pp. 24-25; and Los Alamos Scientific Laboratory, Hot Dry Rock Geothermal Energy Development Project (1977), pp. 38-39.

[3] Jet Propulsion Laboratory, California Institute of Technology, Program Definition for the Development of Geothermal Energy - Volume III: Appendixes (Pasadena, CA: 1975), pp. D19-D20.

In the surface surveys category a plurality of our respondents who yielded a probability assignment were in the 51-75% category. There appears to be some promise of limited contribution in this area. For example, the Bechtel study revealed, "There is no clear and general understanding of the degree to which data produced by the various methods [i.e., magnetotelluric, resistivity, etc.] correlate with each other and with geologic structure at depth."[1] This problem was in part a reflection of the transfer of exploration technology from the mineral, oil, and gas industries which was not wholly adaptable to the unique problems of geothermal exploration.[2] Although most of the literature seems to be concerned with results from surface surveys that are unique to a specific site, there does appear to be a trend in trying to solve the problems pointed out in the above quotation.[3]

For convenience we can combine remote sensing, reservoir simulation, and surface surveys into a general category of indirect resource exploration and assessment methods. In contrast to these indirect techniques subsurface surveys (direct techniques of evaluation) still generate the bulk of reliable information concerning the geothermal resource. Several reports support this position, one of which stated it as follows,

---

[1]The Futures Group, p. 121.

[2]See Energy Research and Development Administration, Geothermal Energy Research, Development and Demonstration Program, pp. 16-17.

[3]For examples, see Richard C. West and James I. Pritchard, "Combined Electromagnetic and Galianic Electrical Resistivity Soundings," in Geothermal Resources Council, Geothermal Energy: A Novelty Becomes A Resource, pp. 713-716, and Gerald W. Hohmann, "Topographic Effect in Resistivity Surveys," same publication, pp. 287-290.

> Exploration . . . can be done by either indirect or direct methods. Indirect methods . . . can yield information on depths to bedrock, types of formations, boundaries of formations, and locations of water-bearing formations. They are relatively inexpensive and are definite aids in selecting sites for test holes. But by themselves, indirect methods rarely give enough information to enable a developer to pin-point and evaluate geothermal resources within the reservoir. For this information, he must go to the more costly direct methods -- drilling test holes and pilot wells.[1]

The implication is that verification of the resource will of necessity still continue to be mostly the burden of on-site drilling efforts. Furthermore, this will naturally require a more intensive use of men and equipment at the site than would be required with the indirect alternatives.

The core of technological impediments in subsurface techniques is in well logging capabilities. For several years efforts have been directed at improving prospects in this area. In fact, improved logging capabilities are a part of the federally sponsored program at Sandia Laboratories to improve drilling capabilities in the industry as a whole.[2] However, even if the technical solutions are found, and results do indicate that progress is being made, some limitation may be encountered because of the market size.[3] In other words, technology that is highly specific to the geothermal industry and cannot be transferred to the oil

---

[1] State of California, Department of Water Resources, Water and Power from Geothermal Resources in California, Bulletin No. 190, December 1974, p. 19.

[2] See Sandia Laboratories, GeoEnergy Technology (no date), pp. 6-7, and Lawrence W. Ball, "Developments in Geothermal Logging Technology," in Geothermal: State of the Art, p. 11

[3] U.S. Department of Energy, Division of Geothermal Energy, Prospects for Improvement in Geothermal Well Technology and Their Expected Benefits (June 1978), pp. 86-87.

and gas industries, and thus realize cost reduction advantages of a broad market, may remain too expensive to be used widely in the geothermal industry.

Drilling Technology

Advances in this area are viewed as critical for reducing costs of exploration and development. One study points out that "drilling the wells requires about one-third of the total investment of a geothermal power system including the power plant itself."[1] Another suggests that conventional drilling technology for geothermal resources is two to four times the expense of drilling to the same depth for oil and gas.[2]

The Department of Energy - Division of Geothermal Energy has initiated a program to develop new drilling and completion techniques with the goal of reducing well costs by 25% by 1982 and by 50% by 1986.[3] However, even if these reductions are realized, it is unclear how much growth will be stimulated in the industry as a result. Therefore, it appears that two crucial factors limiting implementation of new technology in the geothermal industry are the limited market within the industry and the related uncertainty of the degree of cross-fertilization of new geothermal technology with the oil and gas industries.

---

[1] Jet Propulsion Laboratory, Program Definition . . ., Volume III, p. D-31.

[2] D.O.E., Prospects for Improvement in Geothermal Well Technology, p. 90.

[3] S.G. Varnado and H.M. Stoller, "Geothermal Drilling and Completion Techniques Development," in Geothermal Energy: A Novelty Becomes a Resource, pp. 675-678.

The wide distribution of responses to the technological factors listed in our survey reflect a continuing attitude of uncertainty. The general drilling capabilities listed are current practice in the oil and gas industries. However, the high temperatures and abrasive rock formations common to geothermal sites require many improvements in drilling equipment and accompanying materials -- e.g., the factors listed under specific developments.

Related to the program of drilling technology has been the uncertainty of ample availability of drilling rigs. The Bechtel study cited a limited availability of rigs for geothermal drilling.[1] We contacted twelve suppliers and users by telephone and informally interviewed them on the subject (December 1978). They generally agreed that rigs have been in short supply, in particular in the Rocky Mountain area, but opinions were mixed concerning how long the situation would last, some saying that there was full utilization but no shortage and others saying that a surplus was expected. Three manufacturers were expanding their plant capacity in anticipation of a continued increase in demand.

The current problem for the geothermal industry is that drilling for oil and gas is more profitable. One person who was interviewed (on a related subject) said that he knew of at least one case where rigs were switched from geothermal to other types of drilling for this reason.

---

[1] The Futures Group, p. 121.

Reservoir Development

Research in the area of prediction of scaling has apparently been of great use.[1] As our results indicate there is considerable confidence that the problem will be resolved by 1985. This is a key factor in the development of hot water conversion systems. As one group of authors put it, "The single largest obstacle that must be surmounted in order to make geothermal fluids a viable energy resource is the problem of scaling."[2]

Unfortunately, the prediction of subsidence is expected to remain a problem, at least beyond the scope of our 1985 time horizon. This is in part a reflection of inadequate reservoir modeling. In conjunction, subsidence abatement (listed under the environmental heading) also received relatively low scores.

Improved reinjection techniques and the prevention of plugging in reinjection wells are also crucial factors in the development of certain geothermal sites. One researcher states, "The economic viability of geothermal power production at the Salton Sea Geothermal Field will require a long-term capability for injection of brine effluents."[3]

---

[1] See Chapter 4, "Brine Chemistry and Materials," in The LLL Geothermal Energy Program Status Report, and J.D. Rimstidt and H.L. Barnes, "Experiments for Rapid Assessment of the Scaling Properties of Geothermal Fluids," in Geothermal Energy: A Novelty Becomes a Resource, pp. 567-574.

[2] W.F. Downes, H.L. Barnes, R.D. Rimstidt, "Field Scaling Tests on Geothermal Brines," in Geothermal Energy: A Novelty Becomes a Resource, pp. 165-166.

[3] H.A. Sklar, "Evaluation of Injection-Well Performance," in The LLL Geothermal Energy Program Status Report, p. 156.

Our results in the materials category are inconclusive but not as pessimistic as the view put forth by the Division of Geothermal Energy.

> One way to overcome the currently limiting features of geothermal drilling is to develop radically new approaches. These might provide economical drilling that does not involve muds, cements, lubricants, elastomers, or other materials which do not work well at elevated temperature. *An alternative but unlikely possibility is the gradual increase in the performance capabilities of each of these materials.* [Italics added][1]

Well stimulation techniques are important to improve production in marginal reservoirs and to restore older wells to original capacity.[2] It also appears that improvement in this area will be a critical factor in the development of hot dry rock systems.[3]

Control of scaling and corrosion is a key factor in reducing the costs of utilizing geothermal brines since these two impediments lead to higher operating and maintenance costs and a reduced load factor because of down-time for repairs.[4] The Bechtel study revealed that there was a diversity of opinion concerning the resolution of scaling and corrosion problems.[5] Our results indicate that this is still the situation; however, the balance

---

[1] D.O.E.-D.G.E., Prospects for Improvement in Geothermal Well Technology and Their Expected Benefits, p. 94.

[2] Jet Propulsion Laboratory, Program Definition . . . Volume III, P.D-23.

[3] See Los Alamos Scientific Laboratory, Hot Dry Rock Geothermal Development Project, pp. 7-8.

[4] For discussion of this problem and potential solutions see, Jet Propulsion Laboratory, Program Definition . . . Volume III, Appendix D-11, pp. D-63 - D-79, and U.S. Department of Energy, Division of Geothermal Energy, The Results of the Initial Feasibility Program on Cavitation Descaling Techniques for Pipes and Tubes Used in Geothermal Energy Plants (Prepared by Daedalean Associates, Inc., June 1978).

[5] The Futures Group, pp. 257-258.

of respondents scored the potential for solutions in the lower two quartiles, the exception being the factor pertaining to the extraction of useful materials from geothermal brines in which the probability assignments were in the upper two quartiles.[1]

Development of reservoir systems other than dry steam and hot water (brines) will be essential for long-run industry growth. Of the three alternative candidates for development included in our study -- hot dry rock, geopressured, volcanic heat sources -- geopressured received the most favorable estimates. Although the development of geopressured reservoirs are only on the fringe of the time horizon of our study, a few comments are warranted because of its potential to greatly enhance industry growth.[2]

Preliminary investigations of the geopresured resource were quite encouraging, partly because three types of energy may be derived from geopressured waters -- thermal, kinetic, and chemical.[3] However, the following technical uncertainties have been cited in a study by the Jet Propulsion Laboratory.

---

1 For a discussion on how a 10-megawatt pilot has operated in this environment and the problems encountered see U.S. Department of Energy, Division of Geothermal Energy, Geothermal Loop Experimental Facility, by H.K. Bishop, et.al., (January 1978).

2 Some preliminary investigations have been made of the geological formations in the inland Texas Gulf Coast area and have delimited the more promising regions for geopressured energy: U.S. Department of Energy, Division of Geothermal Energy, Geothermal Resources, Wilcox Group, Texas Gulf Coast, by D.G. Bebout, et.al., (January 1978); U.S. D.O.E. - D.G.E., Geopressured Geothermal Fairway Evaluation and Test-Well Site Location Frio Formation, Texas Gulf Coast, by D.G. Bebout, et.al., (January 1978); U.S.D.O.E. - D.G.E., Geothermal Resources, Vicksburg Formation, Texas Gulf Coast, by R.G. Loucks, (January 1978).

3 Jet Propulsion Laboratory, Program Definition . . . Volume III, pp. G-1 - G-2.

(1) The number of aquifers with sufficient volume and permeability to sustain large flows of water over long intervals of time.

(2) The methane gas content in geopressured water. The amount of gas which can be recovered is a primary factor in the economics of utilizing geopressured water.[1]

More recent work points out a third factor.

(3) The most significant environmental concerns are subsidence resulting from the withdrawal of enormous volumes of formation waters and the disposal of highly saline brines.[2]

Energy Conversion

In the literature reviewed there was no significant treatment of carbon steels and titanium alloys. Correspondence with one participant in our study revealed that these materials were already developed to the point where they posed no significant technological barrier.

Given the large mass of literature devoted to specific technology and systems technology of energy conversion, a discussion of each factor would far exceed the intended limits of this study. The references already cited and the bibliography at the end of this part of the study provide an ample starting point for the interested reader.

---

[1] Jet Propulsion Laboratory, Program Definition . . . Volume III, p. G-7.

[2] Thomas C. Gustavson and M.M. McGraw, "Potential Environmental Concerns Associated With the Development of Geopressured-Geothermal Resources of the United States Gulf Coast," in Geothermal Energy: A Novelty Becomes a Resource, pp. 245-248. For recent analyses of the geopressured resource see in the same reference D.E. Hankins, et.al., "Chemical Analysis of Water from the World's First Geopressured-Geothermal Well" (pp. 253-255), and O.C. Karkalits and B.E. Hankins, "Chemical Analysis of Dissolved Natural Gas in Water from the World's First Geopressured-Geothermal Well." (pp. 351-354).

There are apparently a large number of research efforts concentrating in the area of energy conversion technology, sponsored both by the government and by private industry. As this study progressed, some interesting insights were forthcoming from several participants. First, some were highly critical of particular projects that were being funded by the federal government as wasteful and not very promising avenues of approach. Others, in the private sector, indicated that they were "shelving" their research efforts because of lack of government interest. Finally, concern was also expressed about the apparent efforts of some individuals to convince firms to purchase equipment that had not been proven to be technologically sound. This latter factor may be attributable to the lack of information concerning the emerging novel technology in the industry.

One might perhaps deduce that the above observations are not surprising since many of the experts being surveyed probably have vested interests in marketing their own inventions or innovations. However, strict adherence to anonymity for all participants in all phases of this survey was guaranteed. In some cases it was obvious that the participants would gain nothing from their critical comments, and the open and convincing nature of their arguments supported this view.

Environmental

It should be pointed out that this problem has received considerable attention from the federal government in terms of anticipating the effects of future development, devising a plan of assessment, and reviewing existing regulations at the national, state, and local levels.[1] One of these studies makes the following conclusions concerning pollution control technology in the geothermal industry.

> Very few pollution control technologies applicable to geothermal energy conversion systems have been demonstrated. Most of the control technology development and operation of control facilities has been done at The Geysers geothermal power generation station owned by Pacific Gas and Electric Company.
>
> Several pollution control technologies used in other industries appear to be applicable to the geothermal industry, if they are sufficiently economical. However, at present, it appears that many of them will not be economically achievable in situations where they might be technically feasible. It does not appear at this time that any new control technology concepts will be devised for the geothermal industry. Instead already known concepts and their technologies will be adopted.[2]

As was previously mentioned several participants in our study felt that environmental factors would pose serious constraints for future development of the geothermal industry. A very comprehensive environmental analysis of The Geysers in California points out that environmental factors may vary considerably and (in the case of noise abatement) recommends the development of a general assessment methodology.[3] The presence of H_2S is currently a major concern, but some preliminary studies reveal that this

---

[1] U.S. Environmental Protection Agency, Pollution Control Guidance for Geothermal Energy Development, by Robert P. Hartley (June 1978); U.S. Department of Energy, Environmental Development Plan: Geothermal Energy Systems (March 1978); U.S. Environmental Protection Agency, Survey of Environmental Regulations Applying to Geothermal Exploration, Development, and Use, by Mrs. Gene V. Beeland (February 1978).

[2] U.S. Environmental Protection Agency, Pollution Control Guidance for Geothermal Energy Development, by Robert P. Hartley (June 1978), p. 7.

[3] Consultant Report on Environmental Analysis for Geothermal Energy Development in the Geysers Region, Volume II: Master Environmental Assessment, Prepared for California Energy Resources Conservation and Development Commission by Stanford Research Institute (May 1977).

is a manageable problem and is not a serious threat to development.[1] However, the problems of water pollution and especially subsidence appear to be the most serious long-run factors, and these will become more pronounced if the industry continues to grow via development of the hot water and geopressured forms of the resource.

Technology Development in Perspective

In a technology assessment study it is important to keep in mind that one is dealing basically with technical experts and not with manufacturing and marketing experts. Therfore, it is wise to include a few comments from studies which have dealt with these other critical factors of technology development and commercialization. These will serve to lend more perspective to the results of our study (and others) and what might be expected from the geothermal industry.

One study by Frank Lynn was directed at an empirical analysis of twenty major technological innovations that have taken place in this century.[2] Admittedly this is a much broader approach than was the purpose of assessing new technology for a particular newly emerging industry, and

---

[1] For example, see P.H. Gudiksen, et.al., "Air Quality Studies of Geothermal Development in the Imperial Valley," and J.F. Kunze and S.G. Spenser, "Environmental Necessity and Sufficiency: The Case of the Raft River Project," in Geothermal Energy: A Novelty Becomes a Resource, pp. 235-236 and pp. 391-393 respectively.

[2] Frank Lynn, "The Rate of Development and Diffusion of Technology," in Howard R. Bowen and Garth L. Mangum, eds., Automation and Economic Progress (Prentice-Hall, Inc.: Englewood Cliffs, N.J., 1966), pp. 99-113.

this may considerably weaken the validity of the conclusions which can be applied to our study. However, given some of the grandiose projections of geothermal potential and the fact that we may be rather naive in assuming that technical solutions will translate into commercial application, even after a long lag time, we believe these conclusions are at least worth repeating.

In order to preserve some brevity several thought provoking quotes will be given from Lynn's study. Care was taken to try to preserve the context from which the quotes were taken and therfore not to bias the intent.

> The results suggest that the acceleration in the rate of technological development can primarily be attributed to the increasing sophistication and activities of business and industry in identifying potential commercial applications of technology. (p. 105)

> Despite their rather substantial effect on the incubation period [defined as beginning when technical feasibility of an innovation is established, and ending when its commercial potential becomes evident and efforts are made to convert it into a commercial product or process], none of these factors [referring to the historical timing, type of market application (consumer or industrial), source of development funds (private or federal government), and whether or not the innovation was developed in existing (secondary) or new (primary) industries] were shown by this study to have had a significant influence on the commercial development period. Logic would tend to suggest that the rate of commercial development for innovations sponsored by the federal government would be much faster than for those financed by private industry, and that industrial innovations would have a faster rate of commercial development than consumer innovations. But no such pattern was evident from the analysis. Similarly, very little difference existed between the commercial development periods for primary and secondary type innovations. (p. 106)

> From these data, it is apparent that the present rate of development and diffusion of technology does not require the institution of an "early warning system" to identify potential major technological innovations in their early stages of research and development. Almost without exception, those technological innovations that will have a significant impact on our economy and society during the next five years have already been introduced as commercial products or processes. (p. 113)

Other studies are also pointed about the need for potential market assessment, for example, a study by the National Science Foundation concluded the following.

> *Recognition of demand is a more frequent factor in innovation than recognition of technical potential.* The idea or concept for an innovation is necessarily a fusion of recognition of both demand and technical potential. In the present study the innovators indicated that the primary factor in undertaking work on the innovation was a recognized market potential or a recognized need in the production process in three-fourths of the cases. In 21 percent of the cases the primary factor was recognition of a technical potential which might be exploited.[1] [Author's italics]

Finally, in another study, prepared for the National Science Foundation by Arthur D. Little, Inc., the results are also interesting.[2] This study concluded that the most significant technological barriers perceived by industry were market related. This portion of their results is reprinted below.

> There are barriers that are widely perceived as "significant" or higher, and therefore seem not to be industry specific. These barriers are:

---

[1] National Science Foundation, Successful Industrial Innovations (Washington, D.C.: U.S. Government Printing Office, 1969), p. 60.

[2] Arthur D. Little, Inc. and Industrial Research Institute, Inc., Barriers to Innovation and Industry: Opportunities for Public Policy Changes (Prepared for the National Science Foundation, 1973). See pages 18-19.

	Average Barrier Rating[1]
(1) Unavailability of information critical to decision-making -- marketing	3.5
(2) Unavailability of information critical to decision-making -- market characteristics	3.4
(3) Unavailability of information critical to decision-making -- sales potential	3.0

Conclusions

No single technolgical breakthrough is likely to produce an unexpected boom in the geothermal industry. Advances in alternative processes and components will require complimentary research and development in several related areas. A central question that has emerged in this study (and others) concerns the limited size of the market for geothermal technology. This itensifies the reservations of private industry to conduct research and development because of the uncertainty of whether or not new technology can be profitably produced and marketed. On the other hand, the recognition of a currently limited market, but one with potential for considerable future growth, is the argument used to justify government involvement in research, development, and demonstration efforts.

The question of cross-fertilization of geothermal technology with the oil, gas, and mineral industries is also central to the limited market problem. But this question remains largely unanswered. It is recommended that this subject be investigated and incorporated in a cost-benefit framework for government supported technology research.

---

[1]The rating scale was as follows: 0 = No barrier, 1 = Marginally significant barrier, 2 = Moderately significant barrier, 3 = Significant barrier, 4 = Very significant barrier, and 5 = Critical barrier (p. 16).

The technology assessment study has influenced our manpower assessment in several areas. First, it serves to qualify scenerios concerning industry growth and the resultant demand for manpower. In general it appears that progress will continue to be slow but steady with continued growth at The Geysers and Imperial Valley with reasonable assurance that the technical problems (e.g., scaling and corrosion) associated with the latter will be resolved. However, a general industry "boom" will probably only come with the development of the geopressured resource.[1] This prospect is not within our time horizon. Finally, one of the most significant impediments that might be expected in the future is environmental, especially the uncertainty concerning the subsidence problem.

Second, there was a small amount of direct information concerning manpower that was forthcoming from our technology investigation.

(1) Most technical experts in the geothermal industry have come from the oil and gas industries, some having received special geothermal training.

(2) Feedback from some participants indicates that the types of technical personnel currently needed are in earth sciences (e.g., geologists, geophysicists, geochemists, etc.) and engineering (e.g., reservoir, environmental, and mechanical engineering).[2]

---

[1] This possible "boom" is dependent on optimistic estimates of the thermal, kinetic, and chemical energy potential of the geopressured resource. One expert has understandably taken strong exception to a predicted industry boom, predicated on the geopressured resource especially in electrical energy production, with the view that the most impressive growth will occur in direct use applications.

[2] In conjunction, see Vasel W. Roberts, "New Career Paths in Engineering: Geothermal Energy," in Mechanical Engineering (November 1977), pp. 50-53.

Third, as a first stage of the development of the geothermal industry, much technology had to be transferred directly from other industries, particularly oil and gas.[1] We have observed this to be especially true in resource exploration and assessment, drilling, and at least initially in pollution technology. It follows that the required manpower in these areas was also directly transferred from other industries. The second stage of development has been the alteration and adaptation of these and other techniques to the unique features of the geothermal resource. This requires specific training geared to the uniquely emerging industry. This technology study and the personal interview phase of the manpower assessment study reveal that the main method is on-the-job training, not only for scientific and technical personnel but also for skilled labor. The personal interview phase particularly points out that specialized degree offerings in geothermal activities do not exist in educational institutions, although some courses of an orientation nature are available.

It appears that the industry is firmly established in this second stage and the policy issue is whether or not it will soon advance to a third stage involving the emergence of novel technology on a wide scale and/or a significantly increased industry growth rate. The implications of such a course of events would be the greatly increased need for manpower which is

---

[1]The use of the terms stages of development (or growth) makes no pretense to the rigor of its use in the context of economic theory. However, the idea of discussing a newly emerging industry in a developed economy in this context does not appear to be an object of ecnomic inquiry. Still, on the surface at least, it is an intuitively appealing approach as a first step in understanding manpower growth patterns in related industries. We suggest this as a useful avenue of investigation in rationalizing and comparing occupational growth patterns in the various sectors of the energy industry. This would hopefully allow the recognition of common characteristics and problems which would be invaluable for policy guidance.

highly specialized to the geothermal industry, hence the establishment of formal training programs (assuming this to be the least cost approach) capable of producing manpower in adequate quantities ensuring that bottlenecks do not emerge.

Given the results of our inquiries and given the D.O.E. - D.G.E. forecasted industry growth, we conclude that only a modest effort is currently needed - i.e., a few government supported specialized courses of training at formal institutions. This would establish a training base which could be gradually expanded as needed if the industry begins to grow at a more rapid pace in the 1980's.

Finally, in conjunction with our personal interview survey of firms in the private sector, a final factor should be mentioned. Results indicate that resources (capital and labor) are mobile between the geothermal industry and other industries, especially oil and gas. In relation to manpower this was true both in an interfirm-interindustry sense and in an intrafirm case where the firm was engaged in multiple industry efforts.

APPENDIX V-A

EDITED RESPONSES FROM

THE ROUND-ONE QUESTIONNAIRE

I. What have been the major inventive or innovative breakthroughs in geothermal technology in the last five years?

(1) The development and patenting of a new type of vapor or liquid-to-vapor expander, which has much greater potential than any other device in existence for fluids in the geothermal temperature range. The device is called the Roto-Oscillating Vane, Orbital-Piston (ROVOP) machine.

(2) The development of a prime mover, capable of utilizing geothermal hot brines directly.

(3) Improved ability to handle liquid dominated resource fluids.

(4) The potential use of large radial inflow turbines operating with hydrocarbon secondary working fluids, isolating the brines from the turbine area.

(5) The invention of the direct contact binary system for geothermal power conversion.

(6) The development of technology required to produce electricity from the hypersaline brines in the Salton Sea KGRA.

(7) Binary vapor cycles and total flow turbines. However, these are still in the R & D stage and are not yet commercially proven.

(8) Improved resource exploration; increased acceptance of carbon steels.

(9) Speaking for (name of company deleted) only, our breakthroughs include: (a) integrated agribusiness, aquafarming, biogas

generation with geothermal energy in a cycle called "TERSA",
(b) hybrid powerplant using geothermal and wood residue, and
(c) improved cooling pond design for power plant.

(10) Module development.

(11) In-situ acidification of hi-salinity geothermal fluids for scale control and recovery of mineral constituents from geothermal brines.

(12) None that could be classified as major. Steady progress in recent years has been made in demonstrating the technology for handling steam (U.S. and Italy) and water dominated resources (Mexico and New Zealand).

(13) Concerning exploration: Improvements and adaptation of various geophysical exploration techniques, primarily electrical methods (Magneto-tellering, tellers) and seismic methods (micro earthquake studies and seismic attenuation studies using local and teleseismic events as well as manmade services).

(14) In-hole energy conversion and closed systems.

(15) I believe we are trying to invent "the wheel" all over again when we look at geothermal energy development techniques. Why don't we visit New Zealand, Iceland, Russia, Italy, and Japan where they are running geothermal electric energy generating facilities and see where we are failing to recognize and use existing techniques.

(16) (a) Sophistication of computer modeling techniques in reservoir assessment.
(b) Sophistication of well testing.
(c) Sophistication of geochemical methods for predicting parameters deep within geothermal systems.

(d) The development of resistivity as an effective method in geothermal exploration.

(e) The use of satellite data for geothermal reconnaissance studies.

(17) Exploration: (a) geophysical advancement in resistivity and magnetotelluric surveys; (b) geochemical technology in general and gases survey as an exploratory tool; (c) a better and little known understanding of the geology and volcanology (including criptovolcanology) of geothermal field.

(18) In my area of expertise, which is geothermal exploration, I do not believe there has been any major breakthroughs in exploration technology in the last five years.

(19) Refinements in exploration technology -- geophysical, geochemical; heat exchange and total flow utilization systems.

(20) Reservoir engineering and drilling advances.

(21) Recognition that two stage flash equipment in the low temperatures (350°F to 400°F) can produce electricity at prices competitive with fuel oil if the water has less than 15,000 ppm solids.

(22) Technology transfer from other disciplines; geochemical exploration (such as key element logging during drilling).

(23) We haven't seen any breakthroughs for exploration or drilling. Possibly some advancement in geophysics as it applies to geothermal efforts.

(24) (a) Development of hot dry rock energy extraction loops.

(b) Development of new types of conversion equipment, such as the screw expander.

(c) Development and testing of organic-vapor binary cycles.

(d) Development and demonstration of downhole instrumentation.

(25) (a) Demonstration of LASL --Hot Dry Rock Project.

(b) New Maurer Engineering Geothermal Turbodrill.

(c) High temperature logging instruments.

(d) Hydraulic fracturing of growth at LASL.

(26) (a) Downhole pump by Sperry Research Center.

(b) High temperature turbodrill by Maurer Engineering, Inc.

(c) Integrated Thermionic Circuits (ITC); i.e., active, high temperature electronics for service up to 600°C, by LASL.

(d) High temperature, open-hole packers for formation fracturing and stimulation, by Lynes, Inc.

(e) Hybrid, 4 cone plus stratapax core bits for hard geothermal formations, Smith Tool.

(f) The basic technical feasibility of hot dry rock geothermal technology, by LASL.

(27) Two-phase fluid transmission.

(28) (a) Use of titanium alloys in turbines for power generation.

(b) Flash vaporizers for pure water conversion.

(29) Demonstration of technical feasibility of wet dry rock concept.

(30) No major breakthrough seen; rather, strong effort in technology transfer has been taking place.

(31) Development of the down-hole pump and development of the down-hole heat exchanger.

(32) Major emphasis has been added to geothermal due mainly to the upward trend in energy costs in general. Renewed interests in liquid-dominated systems and the accompanying materials/corrosion research has been most significant.

(33) (a) Geothermal well drilling techniques.

(b) Multiple legs for the bottom hole.

(c) Use of transite pipe for fluids below 300°F.

(d) Design and operation of binary power systems including direct contact units.

(34) Very few. Most are using modified oil field practice.

(35) Work in hi-saline geothermal.

(36) Seating and sealing of casing.

II. What do you consider to be current bottlenecks in technology development (capable of being solved by 1985) that would require the introduction of a new invention or innovative technique?

(1) There are no positive-displacement expansion devices being developed which have sufficient expansion ratio capability and exhaust volumetric capacity to provide good efficiency from low energy fluids. The only possible solution currently known is the ROVOP. It is not being developed for lack of minimal funds.

(2) Satisfactory control of mineral deposition in the supply well, process piping, and the disposal well on system.

(3) Improved reliability of systems and components. Improved ability to economically dispose of power plant effluents, such as brine injection, sludge, and gases.

(4) We don't see any restrictions to the use of geothermal power at this time.

(5) Understanding of well stimulation and production limitations.

(6) (a) Downhole pumping.

(b) Pumps, valves, and instrumentation which will operate in a scaling environment.

(c) Methods of silica removal from hypersaline brine.

(7) Environmental impact of waste effluents. In the case of the Geysers, this is primarily hydrogen sulfide. In the area of the Geysers ambient air quality standards for H_2S are being exceeded and regulatory agencies will not allow this to continue indefinitely. This is likely to be a problem at many geothermal projects.

(8) Binary power cycles and heat exchanger automatic descaling.

(9) Realization (or lack of) potentials for severe pollution not yet recognized.

(10) Environmental impact requirements to satisfy government requirements; chemicals contained in geofluids.

(11) Module design.

(12) (a) Lack of venture capital to fund high risk, hi-salinity geothermal reserves for power generation and minerals recovery demonstration plants.

(b) Demonstrated, viable, low-cost, non-corrosive methods for eliminating or lessening scale deposition in high salinity geothermal systems.

(13) None, pertaining to geothermal turbine operation.

(14) (a) Governmental regulations hinder severely any exploration programs although I seriously doubt this is capable of being solved by 1985.

(b) Methods of handling very high concentrations of salts and other solids need to be developed.

(15) (a) Exploration technology.

(b) Drilling technology.

(c) Energy conversion.

(16) Low cost, heat exchanges and turbines for use with temperatures less than 150°C.

(17) The development of techniques to use a geothermal resource in the range of approximately 212°F to 250°F to generate electricity. (Design plant to use a booster fuel such as solar or coal to step up temperature from earth to 350°F/400°F for greater efficiencies.)

(18) (a) Development of well logging tools with dual capabilities.

(b) Development of well logging tools able to operate under more adverse temperature and chemical conditions.

(c) Development of better well drilling and completion methods.

(d) Refinement of interpretation of self-potential surveys in the study of geothermal systems.

(e) Development of better techniques for predicting subsidence.

(19) (a) Development of commercial two-cycle power plants.

(b) Development of space conditioning agricultural facilities.

(c) Production evaluation during drilling, for instance by better geochemical logging and packer tests.

(d) Decrease of the rate of production can be controlled by hydro-fracturing and chemical methods.

(20) The major bottleneck to geothermal resource exploration is the lack of opportunity to explore for the resource. The reason this lack of opportunity exists is due to interference and harrassment of explorationists by various government agencies. If this problem could be solved by an invention then that invention is what we need by 1985.

(21) Masking of the resources by natural means, causing us to use a multitude of techniques to increase the probability of tapping a resource when drilling takes place.

(22) (a) Well logging hardware and technique.

(b) Biggest bottlenecks are not technological; they are legal, environmental, bureaucratic, etc.

(23) (a) Formulation stimulation -- explosive fracturing and mechanical packing.

(b) Advances in drilling technology.

(c) H_2S abatement contained in geothermal fluids.

(24) Acceptance of reservoir engineering (analysis) measurements as confirming the extent of the energy supply.

(25) Downhole measurement instruments capable of operating at temperatures greater than 350°C.

(26) (a) Well stimulation by fracturing.

(b) Effective exploration tools to evaluate areas (such as the Snake River Plain and Cascades) where conductive heat is regionally disturbed in the near subsurface are needed.

(27) It appears government funds are being used mostly for academic welfare rather than actual research and development of new technology. Lots of ideas and reports.

(28) (a) Brine-reinjection techniques.

(b) Conventional and directional drilling equipment.

(c) Higher-temperature downhole instrumentation.

(d) Improved cements.

(e) Improved low-cost high-temperature elastomers.

(f) High-temperature explosives capable of propagating in thin cracks.

(29) (a) Improved drilling equipment.

(b) Improved geothermal drill bits.

(c) Improved geothermal drilling motors.

(d) Improved geothermal coring tools.

(e) Improved high temperature casing (serious limitation).

(30) (a) Improved exploration techniques for hot water resources.

(b) Improvement in drilling costs by approximately 50%.

(c) Development of well stimulation technologies.

(d) Development of borehole tools and instruments for evaluation of fractured reservoirs; especially determination of fracture orientation.

(31) (a) Adequate well logging instrumentation for geothermal environment.

(b) Plugging of reinjection wells.

(c) Reservoir simulation which integrates all important data (geological, geophysical, hydraulic, thermal, salinity, etc.).

(32) (a) Development of better down-hole pumps.

(b) Research dealing with injection of spent fluids.

(c) Binary cycles for lower temperature resources.

(d) Development of hot dry rock, and volcanic heat sources.

(e) Development of geopressured systems for thermal and hydraulic energy, as well as natural gas.

(33) Resource reliability establishment.

(34) Corrosion, pipe plugging, salt disposal.

(35) Inability to use hot brines for power generation; expense of current methods of well drilling and related technology.

(36) (a) Ability to produce wells without scale deposition.

(b) Ability to predict where scale formation will occur in wells and transfer lines, by practical, semi-empirical modeling.

(c) Means of increasing overall conversion efficiency in electric plants from low and moderate temperature brines.

(d) Accurate design ability for wells in two-phase flow.

(e) Increase well productivity and reduce well costs.

(37) Scaling is the primary problem and several techniques will be required for control because of its multiple phases -- oxides, silicates, sulfides, etc.

(38) Better understanding of geothermal reservoirs and their potential; "Total Flow" (mixed steam and water) prime movers.

(39) (a) Decreasing cost of capital equipment.

(b) Flare systems which operate on demand to be used in binary power systems.

(c) Improved drilling techniques or equipment to reduce well costs.

(d) Down hole pumps which operate at high temperature and are inexpensive and easy to install.

(40) Reducing the cost of drilling geothermal wells by 50% will require a new method of drilling, i.e., something different from conventional rotary techniques.

(41) Work in hi-saline geothermal.

(42) Packers from materials viewpoint.

(43) Corrosion of working equipment parts.

III. What technology that is not yet commercially feasible do you expect to become commercially usable by 1985 (i.e., to the extent that it will generally replace current methods)?

(1) The ROVOP expanders for hot water, mixed-phase flow, steam and binary fluid cycles (whatever the fluid) promises such major advantages in power generation from geothermal fluids, that it is difficult to imagine that they might continue to remain undeveloped.

(2) Binary and hybrid energy conversion cycles.

(3) Casting of very large titanium wheels (for high temperature application only).

(4) (a) Direct contact heat exchange.

(b) Well bore pumping.

(c) Well bore gas lift with a secondary fluid.

(d) Removal of noncondensibles directly from the steam.

(5) (a) Bi-phase engines (maybe).

(b) Direct contact heat exchange (limited use).

(c) Helical screw expander (limited use).

(6) Upstream removal of impurities, such as H_2S, from geothermal steam. This will help resolve environmental problems and may improve plant performance and reduce maintenance.

(7) Binary power cycles.

(8) Small geothermal power plants.

(9) Modules for degassing and heat exchange.

(10) Direct flash of hi-salinity geothermal fluids rather than the 2-fluid concept.

(11) It is unlikely that any technology not yet feasible will ever replace steam turbines as a method of converting geothermal energy to electrical power.

(12) (a) Potential extraction of useful minerals from geothermal brines.

(b) Improvements in the "hot dry rock" type of method to enable heat extraction from dry or impermeable rock.

(c) Better understanding of the physical properties of geothermal systems to allow improved geophysical exploration methods on a commercial basis.

(13) (a) Use of hot rock.

(b) Development of deep geothermal wells deeper than 12/15,000 ft.

(c) Use of relatively low heat resource areas such as those below 250°F down to 220°F or 212°F.

(14) Innovative new lower cost drilling techniques may be available.

(15) (a) Binary power plants.

(b) Exploration in areas without surface manifestation using geochemical, geophysical, and geologic advances technology.

(c) Hot water utilization.

(16) I believe that improvements in remote sensing and better high altitude aerial photography coverage including an expansion of the sky lab coverage would be of more use to geothermal exploration than any new technology that is likely to be invented in the next decade.

(17) Expanded use of geothermal-fossil fuel binary systems as studied by City of Burbank under ERDA contract. Such development may occur at IPP site near Lynndyl, Utah.

(18) (a) Total flow utilization.

(b) Improved binary systems.

(c) Hot dry rock extraction systems.

(19) Upstream H_2S abatement technology.

(20) (a) Binary-fluid systems.

(b) Turbo-machinery capable of utilizing directly two-phase fluid output from geothermal wells.

(21) Hydrotracing techniques.

(22) (a) Brine reinjection.

(b) Small well-head generators (e.g., screw expanders).

(c) Organic-vapor cycle conversion systems.

(d) Stimulation techniques for unproductive hydrothermal wells.

(23) Some improvements on the temperature limitations of existing downhole drilling tools.

(24) (a) More general availability of binary fluid power generating turbo machinery; commercial viability of hot water systems will be possible.

(b) Drilling technology, equipment, and experience in large diameter wells for hot water systems.

(c) Large volume, downhole (high temperature) pumps for hot water resources.

(25) (a) Adequate logging trails.

(b) Coupled geochemistry and heat transport simulation models for assessing different fluid reinjection strategies.

(26) (a) Utilization of geothermal power plants for the provision of peak load power.

(b) Wider spread use of geothermal power for non-electric applications.

(27) Large-scale binary conversion systems.

(28) (a) Reinjection of waste brine, reservoir sealing by in-place soil plugging for evaporative ponds.

(b) Use of titanium alloys to limit corrosion costs.

(29) Possibly down hole pumps for maintaining single-phase flows.

(30) (a) Ability to produce wells without scale deposition.

(b) Ability to predict where scale formation will occur in wells and transfer lines, by practical, semi-empirical modeling.

(c) Accurate design ability for wells in two-phase flow.

(d) Increase well productivity and reduce well costs.

(31) (a) Downhole analytical instrumentation for temperature, pressure, pH, conductance, etc.

(b) Helical rotary screw expander for energy recovery.

(32) I think that "Total Flow" prime movers will be the dominant method of power generation, and that cascaded systems where reject heat from the power cycle is used in some other process will be significant.

(33) (a) Direct contact heat exchangers and condensers.

(b) Improved down hole pumps.

(c) Better surface lines (less expensive and easy to install).

(34) (a) Strampay drill bits.

(b) Downhole replaceable drill bits.

(c) Foams for use as drilling fluids.

(35) Much greater direct application.

(36) Corrosion resistant parts.

V

IV. Additional Comments

(1) There has been sufficient moneys allocated and spent by Federal agencies, State agencies, universities, research institutes, and industry during the past eight or ten years in research on geothermal systems and power equipment to have had ten thousand megawatts of geothermal capacity in operation throughout the Western States by this time. Surely, sooner or later, the government and others in the field will begin to seriously look for some economically useful and commercially applicable new technologies. When the time comes, the technologies are ready for development.

(2) Non-technical impediment: The risk nature of geothermal and the inability of electric utilities to take risks.

(3) I do not expect a "breakthrough" in geothermal development. If reliability and economics are proven, the optimum reservoirs will be developed first. As economics improve, less desirable resources will be utilized. Each reservoir may require individual development effort.

(4) Our feeling is that the power generation equipment aspect of geothermal energy (steam turbines, binary turbines, etc.) either in facilities or its associated manpower, will not be a limiting factor for the development of geothermal energy in the U.S. The industry possesses the capacity to easily supply any foreseen growth in the demand for geothermal turbines. This ability to supply geothermal turbines is definitely not a bottleneck.

(5) Technology isn't the geothermal problem. The problem is for

industry, corporations, and small business interests to find and confirm the resource rather than to retrofit. It is probably uneconomical to do so for these groups. The other problem is institutional barriers.

(6) Impediments that may influence or retard geothermal development are certainly not all directly related to technology. For instance, the power companies, both private and public, request actual generation of electricity using geothermal resources and technology, before they want to commit to building that same power plant which is necessary for production -- their attitude is one of disbelief -- if you have the wells and the field, they question how long the resource will last, they question the corrosion, etc., the effect on equipment, etc. They don't have geothermal oriented engineers and other personnel. Basically, I personally think the economics related to geothermal generation of electricity have an adverse effect because these same power companies are faced with the problem of logistics -- i.e., if the cost of producing energy is high, under their rate regulatory agencies they are allowed to pass these higher costs on to the consumer -- if the source of energy is cheap, they are supposed to pass the savings on. They have no incentives.

In your manpower assessment I think you should give consideration to the fact that many if not all of the governmental personnel involved in geothermal activities are what one might call "90 day wonderers" in that investigation will show most of the geothermal specialists were formerly nuclear, coal, hydro (or whatever) educated and when the demand for geothermal specialists arose these people were given 5 or 6 weeks "brush up" orientation courses in geothermal and became the nucleus of our geothermal manpower pool. Now, recently graduates are in limited numbers arriving on the scene who have some education along geothermal lines but again the popular lines are of course nuclear, coal, solar, oil, and gas -- we need to advertise geothermal and its future.

(7) There are three main blocks for a full development of geothermal energy: (a) institutional and environmental obstructions, (b) ignorance, also by some very large petroleum companies, of the existing exploratory techniques, and (c) the uses of geothermal energy in the fields other than the power production are very little understood, whereas they may supply a very large amount of energy. Our knowledge of the geothermal resources, also in the western states, is very poor. The USGS work in this field is impressive, but the Agency has not the means to do what it is needed, that is, a complete report on the geothermal provinces and areas. The major items are: geological frame, the surface manifestations, information on the wells, and comments on the reasons why many of them were unsuccessful. It will take at least two years work for such a report for each state. The bibliography is ample, but it needs to be summarized with the scope of obtaining a general geological picture, as in oil exploration has been obtained by sedimentary basin theory all over the world.

(8) The big bottlenecks are institution/economic. Remove these and private enterprise can take care of the technological ones with exceptional speed and efficiency, as they have done in the petroleum industry.

(9) An increased government funded drilling research program is needed. Industry is not interested in developing the high temperature bits, motors, directional tools, etc., needed because of the small market compared to the oil well market!

COMMENTS FROM ROUND-TWO

QUESTIONNAIRE

(1) A significant contribution to geothermal energy development would occur if more emphasis were placed on geologic methods of exploration. If a solid base of geologic data and high quality geologic mapping were the first stage of exploration, then better interpretation of geophysical data would result. It also seems reasonable to expect that a better selection of which geophysical methods to employ and where to employ them would result. Cost savings would occur as costly geophysical studies with little likelihood of success could be avoided. In 10 years of geothermal exploration, I have continually read and heard that "good exploration involves geology, geophysics, and geochemistry." As a practical matter with a few exceptions, this rarely occurs. The government in requesting proposals for geothermal investigations will not accept geologic studies unless they include geophysics and geochemical studies. A similar requirement that geophysics and geochemistry be tied to geology does not exist. Perhaps D.O.E. should employ a few exploration geologists and geophysicists with practical experience.

(2) I feel that (with) an increased demand for knowledge coupled with the prospect of economic incentives, the private sector will develop the necessary technology.

(3) Your survey does not consider in its full value the importance of geothermal geological investigations in the field, in the labs, and in theory. Substantial advancements are needed.

GENERAL COMMENTS ON ROUND-TWO RESULTS AND MANPOWER NEEDS OF THE GEOTHERMAL INDUSTRY

(1) Considering the large number of casing failures at Cierro Prieto and Wairakei, there is clearly a need for improvement.

(2) The Air Force, - D.O.D. etc. put tens of millions into high temperature elastomers and got zilch. C-H or C-C bonds won't hack it. There is no obvious large commercial market for industry to consider. Coatings to slow permeability may help but the chance for new magic materials is less than zero.

(3) (a) Some gasses survey techniques using very shallow wells (as an example, helium survey) are under investigation. At present, many of us explorationists feel that more research work is needed on this subject. In conclusion, the gasses surveys should be divided in four categories: surface manifestations, very shallow holes (about one meter deep), temperature gradient holes (100-500 meter), and exploratory deep wells.

As a comment on your preliminary evaluation of your survey, in my opinion the large percentage in the "No Judgment" is due to the state of art. The UN Rome Conference (1961) has been considered the official birth of the geothermal energy as a world-wide significant technology. At this time, a few scores of scientists were working in geothermics. The very successful 1970 UN Symposium in Pisa showed a marked progress. The 1975 UN San Francisco Symposium demonstrated that the adolescence stage both of industry and technology has been reached, mainly by the American scientific and industrial work.

Now, we are growing up: a very large scientific research work is currently under way in many countries. We Americans are the leading team. However, at present the geothermal sciences are far from the maturity that oil reached several decades ago. Happily, DOE programs are well planned and well founded. The resulting reports are numerous, adding to the fact finding and theoretical knowledge. But we are perplexed or discordant on many points: hence, the high percentage of the "No Judgment" answers.

(b) Your survey has been centered in the geothermal electricity production. It is a very important sector of utilization of the geothermal energy. In this sector, by my experience, there is not a scarcity of scientists or engineers. The oil industry, the main factor in this field, can provide the necessary manpower relatively easy. After one year of work, a geologist, a geophysicist, a geochemist, and a petroleum engineer can carry out the exploration, evaluation, and development tasks. Several consulting companies with good experience in the geothermal technology are working successfully on exploration, evaluation, development, drilling, and power plant construction. Also the difficult institutional issues (environmental, legal, taxes) can be managed by the oil industry experts or by reliable consultants.

This optimistic opinion on the present availability of manpower in geothermal electric production cannot be extended to other fields of geothermal utilization. Your survey does not cover this sector.

In my opinion, space heating, agribusiness, and other uses of high or low enthalpy geothermal fluids should be more important than the power production. In these fields, Iceland obtained big successes starting in the early '30s, and continues to improve and develop in a very remarkable way. Russia, Romania, Hungary, Japan, New Zealand, France, and some other countries are also very active.

In our country, we can recognize only some limited activity in Oregon, Idaho, and California. The Oregon Institute of Technology (Klamath Falls) is providing very good basic research work.

However, manpower, as well as technological and industrial development, is scarce and a serious effort should be made in this very important sector. In my opinion, the non-electric uses of geothermal energy may be in the future more important than the power generation.

(4) Because of the state of development of the industry, its current manpower needs are largely for geologists and geophysicists for exploration work and drilling engineers and trained drilling crews for field development. As time goes on and commercial energy production increases, there will be increasing needs for reservoir engineers and chemical engineers to handle field production, corrosion and scaling problems, and fluid disposal; mechanical and electrical engineers to design and control power plants and fluid-distribution systems; and steam-fitters, plumbers, power-plant operators, linemen, etc. to work with fluid production, electrical-power generation, and hot-water, steam, and electricity distribution.

COVER LETTERS AND QUESTIONNAIRES

FOR ROUNDS ONE AND TWO

THE
UNIVERSITY
OF UTAH

HUMAN RESOURCES INSTITUTE

ROOM 412
COLLEGE OF BUSINESS BUILDING
SALT LAKE CITY, UTAH 84112
(801) 581-6127

April 4, 1978

Dear Sirs:

Possibilities of rapid expansion in the development of geothermal energy resources have focused attention on the potential manpower requirements of such development.

The Department of Energy has asked us to conduct a survey of employment by occupation in geothermal related activities during 1977 as a base from which to project manpower requirements to 1985.

As a supplement to this investigation, we are examining technology developments in the geothermal industry in order to take into consideration breakthroughs or impediments that may influence our manpower assessment and forecast. Toward that end we would greatly appreciate a few minutes of your time in replying to the enclosed questions. Please feel free to attach any comments that you think may contribute to our understanding of geothermal technology developments (e.g., names and addresses of individuals you feel we should contact for additional information).

Sincerely,

Richard L. Hannah

R.L. Hannah
Research Economist

RLH:gl

Encls.

V

Name_______________________

Address_______________________

____

Office Phone_______________________

Areas of Expertise (x)

Resource exploration and appraisal ___
Reservoir development ___
Energy conversion ___
Environmental ___
Other (please list)_______________

____

What have been the major inventive or innovative breakthroughs in geothermal technology in the last five years?

What do you consider to be current bottlenecks in technology development (capable of being solved by 1985) that would require the introduction of a new invention or innovative technique?

What technology that is not yet commercially feasible do you expect to become commercially usable by 1985 (i.e., to the extent that it will generally replace current methods)?

Would you be willing to participate in follow-up questioning? Yes_____ No_____
By written correspondence_____ By telephone_____ By personal interview _____

Additional comments (Please use back if needed):

May 18, 1978

Dear Sir:

As was mentioned in our letter of April 4, 1978, we are investigating technological developments in the geothermal industry. The Department of Energy has asked us to estimate manpower requirements by occupation up to 1985, assuming D.O.E. development scenarios for the geothermal industry. Knowledgeable assessments of technological progress are necessary as a basis for such employment projections.

Since we have not yet heard from you, we would very much appreciate your reply. A second copy of our questionnaire is being enclosed in case you have misplaced the first. Each person's response is considered vital, since we are dealing with a select group of experts. Your help will be greatly appreciated.

Sincerely,

Richard Hannah

Richard Hannah
Research Economist

RH:gl

Encls.

THE
UNIVERSITY
OF UTAH

HUMAN RESOURCES INSTITUTE

ROOM 412
COLLEGE OF BUSINESS BUILDING
SALT LAKE CITY, UTAH 84112
(801) 581-6127

Dear

We appreciated very much receiving your response to our Delphi Survey of the state of the art of technology development in the geothermal industry. Our initial correspondence of April 4, 1978 to approximately one hundred experts in various geothermal related activities has resulted in better than a forty percent usable response rate. The responses have been edited and what emerged as controlling factors are presented in the enclosed questionnaire for a second round of evaluation in hopes that some concensus may evolve. For simplicity, comments from other miscellaneous classifications have been listed under the category with which they appeared to be most closely associated.

We ask that you please respond to these results based on the following question and explanation:

> Given your area of specialization, with what probability do you expect advancing technology to enable the factors listed to make a significant contribution to the geothermal industry by 1985?

Significant contribution cannot be precisely defined or quantified, but any technical development which (a) removes a serious technical impediment to the development of geothermal energy resources, (b) contributes substantially to the solution of unresolved problems in the production, development or practical use of geothermal energy, or (c) contributes directly and substantially to an increase in the production and practical application of geothermal energy can be considered to be making a significant contribution.

We ask that you please respond at your earliest possible convenience. Your continued support of our Delphi Survey of technology developments in the geothermal industry is greatly appreciated.

Sincerely,

Richard Hannah
Research Economist

RH:gl

7 11

GEOTHERMAL MANPOWER PROJECT/HUMAN RESOURCES INSTITUTE/UNIVERSITY OF UTAH
Delphi Survey of Technology Developments in the Geothermal Industry/Second Round

Would you like a copy of the final results of this study? ___ Yes ___ No
(Please Check)

	Likelihood of significant contribution by 1985				Present sophistication does not require further technological development	No Judgment
	0-25%	26-50%	51-75%	76-100%		
I. Resource Exploration/Appraisal						
Remote sensing						
Satellite imagery						
High altitude aerial photography						
Surface surveys						
Magnetotelluric						
Microearthquake						
Resistivity						
Subsurface surveys						
Key element logging during drilling						
Gasses survey as an exploratory tool						
Development of well logging tools with multiple capabilities that can operate under high temperatures (250°C-350°C) and under adverse chemical conditions						
Integrated thermionic circuits (up to 600°C)						
Reservoir simulation						
Computer modeling						
Physical modeling						
II. Drilling Technology Advances						
General advanced capabilities						
Wells deeper than 12-15,000 feet						
Multiple legs for bottom hole						
Directional drilling capabilities						
Specific developments						
Improved drilling motors						
Improved drill bits						
Downhole replacable drill bits						
Improved coring tools						
Advances in high temperature casing						
Improved methods of seating and sealing of casing						
Drilling of large diameter wells for hot water systems						
Use of foams for drilling fluids						
III. Reservoir Development						
Prediction						
Prediction of where scaling will occur in the reservoir/energy conversion system						
Prediction of subsidence						
Reinjection						
Improvement or reinjection techniques						
Plugging reinjection wells						

(Please Check)

	Likelihood of significant contribution by 1985				Present sophistication does not require further technological development	No Judgment
	0-25%	26-50%	51-75%	76-100%		
III. Cont.						
Materials						
High temperature open hole packers for formation fracturing & stimulation						
Improvements in down hole pumps						
Cements						
High temperature elastomers						
High temperature explosives						
Stimulation						
Mechanical fracturing						
Explosive fracturing						
Hydraulic fracturing						
Well stimulation with secondary fluid						
Scaling and corrosion						
Extraction of useful materials from geothermal brines						
Removal of noncondensibiles directly from steam						
In-situ acidification of high salinity fluids for scale control & removal of mineral constituents						
Silica removal from hypersaline brine						
Future development of reservoir systems						
Hot dry rock energy extraction loops						
Geopressured systems for thermal energy, hydraulic energy, and/or natural gas						
Volcanic heat sources						
IV. Energy Conversion						
Materials						
Carbon steels						
Titanium alloys						
Specific technology						
Large radial inflow turbines capable of isolating brines from the turbine area						
Pumps, valves, & instrumentation which will operate in a scaling environment						
Heat exchanger automatic descaling						
Heat exchangers for less than 150°C use						
Down hole heat exchanger						
Direct contact condensers						
Well head generator (screw expander)						
Turbines for less than 150°C use						
Total flow turbines						
Flash vaporizers for pure water conversion						
Systems technology						
Use of multiple stage flashing systems						
Direct flash of high salinity geothermal fluids						
Binary power cycles (with separated working fluid)						

V 1

(Please Check)

	Likelihood of significant contribution by 1985				Present sophistication does not require further technological development	No judgment
	0-25%	26-50%	51-75%	76-100%		
IV. Cont.						
Direct contact binary cycle						
Total flow utilization systems						
Hybrid power plants						
Cascaded energy systems						
V. Environmental						
Improved economic disposal of power plant effluents--e.g., brine reinjection, sludge, gases						
H_2S abatement						
Noise abatement						
Subsidence abatement						
Water pollution abatement						
VI. Other (please identify)						

VII. Comments

BIBLIOGRAPHY

V 15

ARTICLES

1. "Artificial Wells Boost Geothermal Potential." Engineering News-Record 198 (June 1977): 42.

2. Aronson, Robert B. "Tapping Nature's Boiler Room." Machine Design 49 (September 1977): 28-34.

3. Austin, A.L., and Lundberg, A.W. "Electric Power Generation from Geothermal Hot Water Deposits," Geothermal Energy Magazine, May 1976, 46-53.

4. Cathles, L.M. "An Analysis of the Cooling of Intrusives by Ground-Water Convection which Includes Boiling." Economic Geology 72 (August 1977): 804-826.

5. Chou, C.S.; Ahluwalia, R.K.: and Woo, E.Y.K. "Regenerative Vapor Cycle with Isobutane as Working Fluid." Geothermics 3 (September 1974): 93-99.

6. Citron, Ora R. "Institutional and Environmental Aspects of Geothermal Energy Development." Nuclear Technology 34 (July 1977): 38-42.

7. Coury, G.E. "Two-Phase Flow in Geothermal Brine Wells." Chemical Engineering Progress 73 (July 1977): 87-88.

8. DiPippo, Ronald. "An Analysis of an Early Hybrid Fossil-Geothermal Power Plant Proposal." Geothermal Energy Magazine, March 1978, 31-36.

9. "Energy Sources: Solar and Geothermal." Power 121 (September 1977): 56-59.

10. "General Electric Awarded Contract to Test New Drilling System." Geothermal Energy Magazine, February 1977, 41.

11. "Geothermal Activity Picks Up On Federal Acreage." Petroleum Engineer 47 (July 1974): 89.

12. "Geothermal Pump To Tap Deep, Hot Brine." Machine Design 47 (May 1975): 12.

13. "Geothermal Research Encouraging." Machine Design 48 (December 1976): 6.

14. Greider, Bob. "Geothermal Energy Task Force Testimony." Geothermal Energy Magazine, March 1978, 14-25.

15. Hinrichs, Thomas C., and Falk, Harry W., Jr. "The East Mesa 'Magmamax Process' Power Generation Plant." Geothermal Energy Magazine, January 1978, 44-45.

16. Holt, Ben. "Geopressured Resource: A Sleeping Giant." Hydrocarbon Processing 56 (July 1977): 98-100.

17. Hornburg, C.D. "Geothermal Development of the Salton Sea." Chemical Engineering Progress 73 (July 1977): 89-94.

18. Hunsbedt, A.; Kruger, P.; and London, A.L. "Recovery of Energy From Fracture - Stimulated Geothermal Reservoirs." JPT: Journal of Petroleum Technology 29 (August 1977): 947-950.

19. "Iceland Harnesses Heat From Lava While Geothermal Projects Gather Steam." Engineering News - Record 198 (May 1977): 25.

20. Krieger, James H. "Geothermal Energy Stirs Worldwide Action." Chemical and Engineering News 53 (June 1975): 21-23.

21. Kruger, Paul. "The NSF/RANN FY 1975 Program for Geothermal Resources Research and Technology." Geothermal Energy Magazine, April 1975, 15-20.

22. Kunze, J.F.; Whitbeck, J.F.; Miller, L.G.; and Griffith, J.L. "Making Electricity From Moderate Temperature Fluids." Geothermal Energy Magazine, October 1976, 7-16.

23. Matthews, Hugh B. "Chevron Tests Downhole Geothermal Pump." Petroleum Engineer 49 (July 1977): 82-84.

24. McNamara, Jack. "Geothermal Reservoir Assurance -- A Problem That Must be Faced." Geothermal Energy Magazine, February 1978, 24-26.

25. Mortensen, Jeannette J. "The LASL Hot Dry Rock Geothermal Energy Development Project." LASL Mini-Review 77-8 (July 1977).

26. Mukhopadhyay, Asok K. "Economic and Engineering Implications of the Project Independence 1985 Geothermal Energy Output Goal and the Associated Sensitivity Analysis." Geothermal Energy Magazine, December 1976, 15-24.

27. Mulkin, Barb. "Steam from Hot, Dry Rocks: LASL's Geothermal Project Gets Steam." Los Alamos Scientific Laboratory Reprint from The Atom (December 1977).

28. Murphy, H.D.; Lawton, R.G.; Tester, J.W.; Potter, R.M., Brown, D.W.; and Aamodt, R.L. "Preliminary Assessment of a Geothermal Energy Reservoir Formed by Hydraulic Fracturing." Society of Petroleum Engineers Journal 17 (August 1977): 317-326.

29. Narath, A. "Advanced Drilling Technology." Geothermal Energy Magazine, June 1975, 8-17.

V. 11

30. "New Drill Bits Hold Geothermal Promise." Geothermal Energy Magazine June 1975, 5-7.

31. "New Type Turbodrill for Geothermal Well Drilling to Get DOE Test in New Mexico." Geothermal Energy Magazine March 1978, 13.

32. "Nippon Puts Heat on Geothermal Power." New Scientist 74 (June 1977): 717.

33. Olson, Harry J. and Dolan, William M. "Geothermal Energy - An Industry Appraisal." Mining Congress Journal 62 (March 1976): 18-21.

34. "Passive Seismic Exploration Program." Geothermal Energy Magazine November 1975, 27.

35. Reynolds, John T. and Wagner, C. Gregory. "Application of Satellite Imagery to Geothermal Resources Exploration." Geothermal Energy Magazine, May 1975, 45-54.

36. Roberts, Vasel W. "New Career Paths in Engineering: Geothermal Energy." Mechanical Engineering 99 (November 1977): 50-53.

37. Robertson, D.E.; Crecelius, E.A.; Fruchter, J.S.; and Ludwick, J.D. "Mercury Emissions from Geothermal Power Plants." Science 196 (June 1977): 1094-1097.

38. Rowley, John C. "Geothermal Energy Development." Physics Today 30 (January 1977): 36-45.

39. "Sandia Laboratories Develops New Logging Tool." Geothermal Energy Magazine, April 1978, 24-25.

40. Sheinbaum, I. "Direct Contact Heat Exchangers in Geothermal Power Production." Geothermal Energy Magazine, August 1975, 13-21.

41. Sheinbaum, I. "Geothermal Well Stimulation with a Secondary Fluid." Geothermal Energy Magazine, January 1978, 33-38.

42. Sheinbaum, I. "Power Production from High Temperature Geothermal Waters." Geothermal Energy Magazine, October 1976, 17-24.

43. Stengel, R.F. "Rotary Separator/Turbine Handles Geothermal Brines." Design News 33 (May 1977): 40-41.

44. Swearingen, J.S. "Power From Hot Geothermal Brines." Chemical Engineering Progress 73 (July 1977): 83-86.

45. Takahashi, Patrick K. and Chen, Bill. "Geothermal Reservoir Engineering." Geothermal Engineering Magazine, October 1975, 7-22.

46. Tien-Chang Lee. "On Shallow-Hole Temperature Measurements -- A Test Study in the Salton Sea Geothermal Field." Geophysics 42 (April 1977): 572-583.

47. Toronyi, R.M. and Ali, S.M. Farouq. "Two-Phase, Two-Dimensional Simulation of a Geothermal Reservoir." Society of Petroleum Engineers Journal 17 (June 1977): 171-183.

48. "Volcanic Energy Harnessed for Hawaii." Electronics and Power 22 (June 1976): 22.

49. Wehlage, E.F. "Needed: Effective Heat Transfer Equipment." Mechanical Engineer 98 (August 1976): 27-33.

50. Wehlage, Edward F. "Two-Phase Energy Conversion Methods." Geothermal Energy Magazine, January 1977, 30.

51. Wilson, J.S. "A Geothermal Energy Plant." Chemical Engineering Progress 73 (November 1977): 95-98.

BOOKS

1. Ayres, Robert U. Technological Forecasting and Long-Range Planning. New York: McGraw-Hill Book Co., 1969.

2. Berman, Edward R. Geothermal Energy. Park Ridge, N.J.: Noyes Data Corporation, 1975.

3. Cetron, Marvin J. Technological Forecasting. New York: Technological Forecasting Institute, 1969.

4. Dorf, Richard C. Energy Resources & Policy. Reading, Massachusetts: Addison-Wesley Publishing Company, 1978.

5. Evans, Larry. Production Technology Advancements: A Forecast to 1988. Ann Arbor, Michigan: Industrial Development Division, Institute of Science and Technology, University of Michigan, 1973.

6. Gewald, K. "The Delphi Method As An Instrument of Technological Forecasting - Practical Experience." In Technological Forecasting in Practice, 13-18. Edited by Hans Blohm and Karl Steinbuck, trans. Frederick and Christine Crowley. Lexington, Massachusetts: Lexington Books, 1972.

7. Herman, Stewart W., and Malefatto, Alfred J. Energy Futures: Industry and New Technology. Cambridge, Massachusetts: Ballinger Publishing Company, 1977.

8. Linstone, Harold A. and Turoff, Murray, editors. The Delphi Method: Techniques and Applications. Reading, Massachusetts: Addison-Wesley Publishing Company, 1975.

9. McMullan, J.T.; Morgan, R.; and Murray, R.B. Energy Resources and Supply. Chichester: John Wiley & Sons, 1976.

10. Wahl, Edward F. Geothermal Energy Utilization. New York: John Wiley & Sons, 1977.

DOCUMENTS, REPORTS, AND PROCEEDINGS

1. Austin, Arthur L.; Lundberg, Anders W.; Owen, Larry B.; and Tardiff, George F. The LLL Geothermal Energy Program Status Report, January 1976 - January 1977.

2. Consultant Report on Environmental Analysis for Geothermal Energy Development in the Geysers Region - Volume II: Master Environmental Assessment. Prepared by Stanford Research Institute for the California Resources Conservation and Development Commission. May 1977.

3. Federal Energy Administration. Project Independence: Geothermal Energy. Washington, D.C.: U.S. Government Printing Office, 1974.

4. Geothermal Resources Council. A Conference on the Commercialization of Geothermal Resources. San Diego, California: n.p., 1978.

5. Geothermal Resources Council. Direct Utilization of Geothermal Energy. San Diego, California: n.p., 1978.

6. Geothermal Resources Council. Geothermal Energy: A Novelty Becomes A Resource. Hilo, Hawaii, n.p., 1978.

7. Geothermal Resources Council. Geothermal: State of the Art. San Diego, California: n.p., 1977.

8. Jet Propulsion Laboratory. Program Definition for the Development of Geothermal Energy, Volume I: Background and Program Definition Summary; Volume II: Program Definition Development Rationale and Subprogram Descriptions, Volume III: Appendixes, 1975.

9. Los Alamos Scientific Laboratory. Hot Dry Rock Geothermal Energy Development Project: Annual Report, Fiscal Year 1977.

10. Sandia Laboratories. GeoEnergy Technology. Albuquerque, New Mexico: n.p. (no date).

11. Second U.N. Symposium on the Development and Use of Geothermal Resources, 3 Volumes. San Francisco, 1975.

12. State of California, The Resources Agency, Department of Water Resources. Water and Power from Geothermal Resources in California. 1974.

13. The Futures Group. A Technology Assessment of Geothermal Energy Resource Development. Washington, D.C.: U.S. Government Printing Office, 1975.

14. Trehan, Ranir K.; Leigh, John G.; Williams, Felicia; and Pond, Susan. *Analysis of Geothermal Energy Development Scenarios*. n.p., 1976.

15. U.S. Department of Energy. *Environmental Development Plan*. Springfield, V.A.: National Technical Information Services, 1978.

16. U.S. Department of Energy, Division of Geothermal Energy. *Geopressured Geothermal Fairway Evaluation and Test-Well Site Location, Frio Formation, Texas Gulf Coast*, by D.G. Bebout, R.G. Loucks, and A.R. Gregory. Springfield, VA: National Technical Information Service, 1978.

17. U.S. Department of Energy, Interagency Geothermal Coordinating Council. *Geothermal Energy, Research, Development and Demonstration Program*. Washington, D.C.: Division of Geothermal Energy, 1978.

18. U.S. Department of Energy, Division of Geothermal Energy. *Geothermal Loop Experimental Facility*, by H.K. Bishop, C.S. Cooney, W.H. Hanenburg, N.C. Hodgdon, W.O. Jacobson, K.K. Li, and C.R. Swanson. Springfield, VA: National Technical Information Service, 1978.

19. U.S. Department of Energy, Division of Geothermal Energy. *Geothermal Resources, Vicksburg Formation, Texas Gulf Coast*, by R.G. Loucks. Springfield, VA: National Technical Information Service, 1978.

20. U.S. Department of Energy, Division of Geothermal Energy. *Geothermal Resources, Wilcox Group, Texas Gulf Coast*, by D.F. Bebout, V.J. Gavenda, and A.R. Gregory. Springfield, VA: National Technical Information Service, 1978.

21. U.S. Department of Energy, Division of Geothermal Energy. *Prospects for Improvement in Geothermal Well Technology*. Springfield, VA: National Technical Information Service, 1978.

22. U.S. Department of Energy, Division of Geothermal Energy. *The Results of the Initial Feasibility Program on Cavitation Descaling Techniques for Pipes and Tubes Used in Geothermal Energy Plants*. Springfield, VA: National Technical Information Service, 1978.

23. U.S. Energy Research and Development Administration, Division of Geothermal Energy. *Geothermal Energy Research, Development & Demonstration Program*. 1977.

24. U.S. Environmental Protection Agency. *Pollution Control Guidance for Geothermal Energy Development* by Robert P. Hartley. Springfield, VA: National Technical Information Service, 1978.

25. U.S. Environmental Protection Agency. _Survey of Environmental Regulations Applying to Geothermal Exploration, Development, and Use_, by Mrs. Gene V. Beeland. Springfield, VA: National Technical Information Service, 1978.