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Hydrothermal Geothermal Resources and Growth in Utilization

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Abstract

The technology for commercialization of vapor dominated hydrothermal geothermal systems has been demonstrated worldwide. Although water dominated hydrothermal geothermal systems produce significant amounts of electric power in several countries, its commercialization has not been demonstrated in the United States. Utilization of the geopressure and hot-dry rock geothermal resources is still in the R&D stage and not likely to impact significantly on total geothermal energy power production until the last decade of the century. Thus, the growth in utilization of the hydrothermal resource is of paramount importance in the near- to mid-term development of a geothermal industry in the U.S.

An analytical relationship has been developed between the temperature and the number of hydrothermal systems. The information is sufficient to estimate various levels of potential development of the hydrothermal resources with temperatures high enough for electric power generation ($T > 150°C$) from a low of 100 up to a high of 450 for the eleven western states. Some impacts of the temperature distribution of this resource are examined.

Previous estimates of the growth of geothermal electric power production are examined and it is found that all but the most conservative are too high for 1985. The present estimate for 1985 is less than 4000 MWe installed. The previous high estimates were all based on a significant increase in the growth rate of geothermal generation capability, usually occurring in the late '70s. The present information shows the past rate of installing generating capacity and its estimated growth to 1985 to be at the rate of 10x every 10 years. This is a large growth rate and should it continue to 1990, the installed MWe will be 10,000. The introduction in utilization of water dominated systems in the early 1980s is necessary for this achievement. The introduction of power generation from geopressure and hot-dry rock resources is necessary for continued high growth beyond 1990.

Introduction

The near-term utilization of geothermal energy in the United States is dependent on many factors. A complete discussion of this topic could lead us into at least all or some of the following areas:

1) Evaluation of the resource base
2) Estimates of growth in utilization and the assumptions in these estimates
3) The risks as perceived by utilities and how these will affect the growth
4) A wide gamut of institutional issues -- which affect development from exploration through power production
5) Environmental problems
6) Financing

All these topics are important to the near-term utilization. The key issue in this is: what's out there -- what is the resource? Much of the information that we have on the geothermal resource is due to long-term careful work by the U.S.G.S. This work was going on during the 40's and 50's long before geothermal energy was considered an attractive alternate energy source.

During that period other important efforts which led to the first successful U.S. commercialization at the Geysers in 1960 were also being made by the farsighted geothermal pioneers. After discussing the resource I will address the growth in utilization. I will discuss some of the other areas as appropriate. It is my belief that this approach will most clearly focus on the utilization of geothermal energy in the next 10-15 years.

Figure 1 lists the classification of the geothermal resource types and the status of their utilization. This information indicates that the hydrothermal convection systems will dominate the utilization of geothermal energy until near the end of the century. Therefore, an analysis of the potential of hydrothermal convective systems is essential to understanding the growth in utilization of geothermal energy in the next 15 years. All current utilization of geothermal energy is from the hydrothermal convective systems.

CLASSIFICATION OF GEOTHERMAL RESOURCES

SYSTEM TYPE	*WHEN UTILIZABLE*
HYDROTHERMAL CONVECTION	
Vapor Dominated	now
Water Dominated	now-soon
HOT IGNEOUS	
Solidified	late 1980's
All or Partially Molten	unknown
CONDUCTION DOMINATED	
Geopressure	late 1980's
Normal Pressure	unknown
Normal Gradient or Basement	unknown

Figure 1

Figure 2 examines the hydrothermal convection systems in more detail. Over 99% of the production of electric energy from geothermal comes from naturally occurring steam or high grade water dominated systems which flash easily into steam. These are the systems which are least common in occurrence and in a true sense we are hy-grading the geothermal resources capable of electric generation. This parallels the past development of other natural resources. An interesting feature of this table is that the lowest grade hydrothermal resource is providing the largest energy utilization world wide. This makes geothermal energy somewhat unique from other natural resources in that the lowest grade resources can and are being heavily utilized while the major high grade resources still exist. This is not the case in the United States where 522 MWe are generated at the Geysers and less than 16 MWt elsewhere in non-electric uses. This situation is certainly a reflection of many different institutional factors operating in the countries involved; it appears likely that the institutional factors in the United States will cause this ratio to continue into the near future.

HYDROTHERMAL CONVECTION SYSTEMS

TYPE	*NUMBER OF SYSTEMS*	*1975 WORLD WIDE GENERATION*	*UTILIZATION TECHNOLOGY*
VAPOR DOMINATED (200°–240°C)	4	973 MWe	Steam Turbines
WATER DOMINATED			
High Temperature High Grade (>210°C)	9	336 MWe	Flash Steam to Steam Turbines
High Temperature Lower Grade (150°–210°C)	0	0	Binary Cycle
Moderate Temperature (90°–150°C)	large	~5000 MWt	Heating, Cooling, Drying
Low Temperature (50°–90°C)	large		Heating, Baleanology, Argiculture

Figure 2

The U.S.G.S. (Ref. 1) has recently assessed the geothermal resources of the United States. Figure 3 lists a summary of their results. This figure provides several pieces of important information. 1) The least abundant energy source is the one currently capable of extensive development. 2) The estimated electrical potential for this least abundant resource type is large. The energy content equals 8000 MWe cent identified with 4x that inferred; this is large enough to provide significant electrical generation capability in the western regions of the United States where these resources are located. 3) The energy potential in the other geothermal resource types for which the utilization technology is in the research stage -- is orders of magnitude larger than the convective systems and represents an almost unlimited potential.

ESTIMATED HEAT CONTENT
U.S. Geothermal Resources

	10^{18} CALORIES	%	RELATIVE AMOUNTS
HYDROTHERMAL CONVECTION			
Vapor Dominated	~50	0.0006	1
Water Dominated			
Electric >150°C	~1600	0.0194	31
Non-Electric <150°C	~1400	0.0170	28
HOT IGNEOUS	~100,000	1.21	2000
CONDUCTIVE			
Geopressure	~140,000	1.70	2830
Normal Gradient	~3,000,000	97.05	~∞

Reference: USGS

Figure 3

Distribution of Hydrothermal Convection Systems

The hydrothermal convection systems reflect in some ways the temperature, extent and frequency of occurrence of heat sources near the earth's surface. It is for this reason that they play so prominent a role in exploration for geothermal resources. The largest numbers of hydrothermal convection systems are found at the lower temperatures. As the temperatures increase there should be a sharp decrease in the number of systems and at the highest temperatures the occurrence should be limited to just a few systems. Hopefully, an examination of the distribution of systems versus temperature would behave in an orderly manner. If so, it might be possible to improve our understanding of them.

The data contained in Waring "Thermal Springs of the World"(Ref. 2) and in U.S.G.S. Circular 726 "Assessment of Geothermal Resources of the United States - 1975"(Ref. 1) provide the basic information for this examination.

Waring's book is an attempt to tabulate information on all the known hot springs, warm springs, fumeroles, etc. Well over 1000 individual spring groups are listed in Waring for the eleven western states. The temperature of the water at the surface is given for about 800 springs or hot spring groups. The temperature data in Waring on the thermal springs in the eleven conterminous western states and plotted in Figure 4 as frequency versus 5° temperature increments. Observe that the distribution versus temperature is as expected, the larger population occurs at the lower temperatures and drops off rapidly as temperature increases. 214 systems listed only as hot and warm will impact most heavily in the lower half of the temperature range making the expected distribution more pronounced.

Figure 5 plots the temperature as a function of the logarithm of the accumulated number of systems. This suggests a log-normal plot common to many other naturally occurring systems. The apparent distribution decrease at lower temperatures is probably the result of sampling, i.e., ignoring lower temperature systems. The conclusion about the distribution is that a linear relationship exists between the logarithm of the total number of systems and temperature.

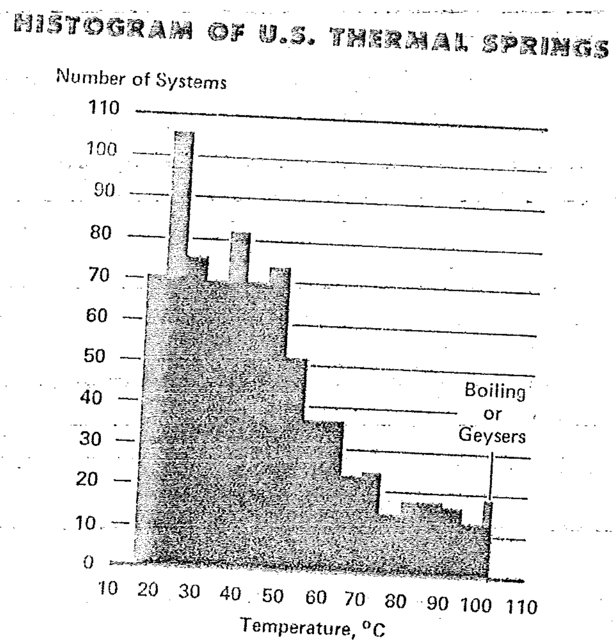

Figure 4

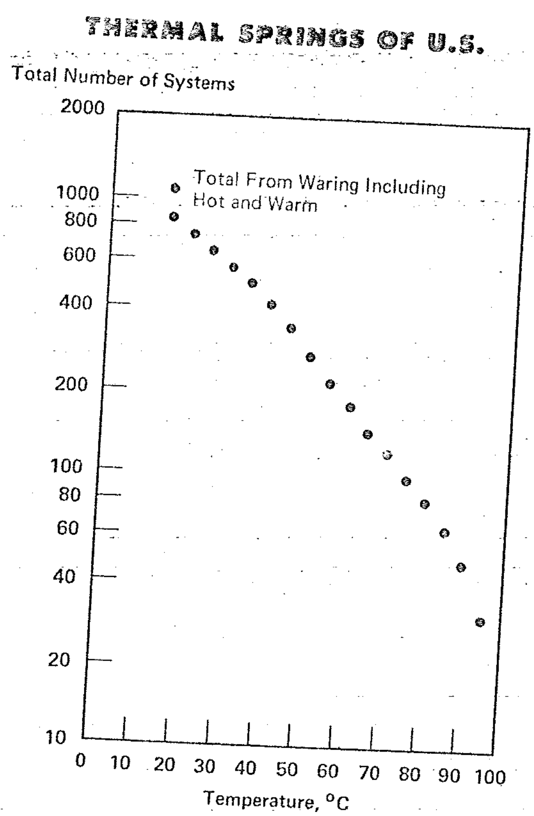

Figure 5

Circular 726 assesses all the geothermal resource types. It also assesses the hydrothermal convective resources of the U.S. from data that is available to the U.S.G.S. on 257 systems that have indicated subsurface temperatures greater than 90°C.

Figure 6 plots my compilation of the data contained in Circular 726 for the 257 systems. This curve also shows a strong linear relationship between log total number versus temperature.

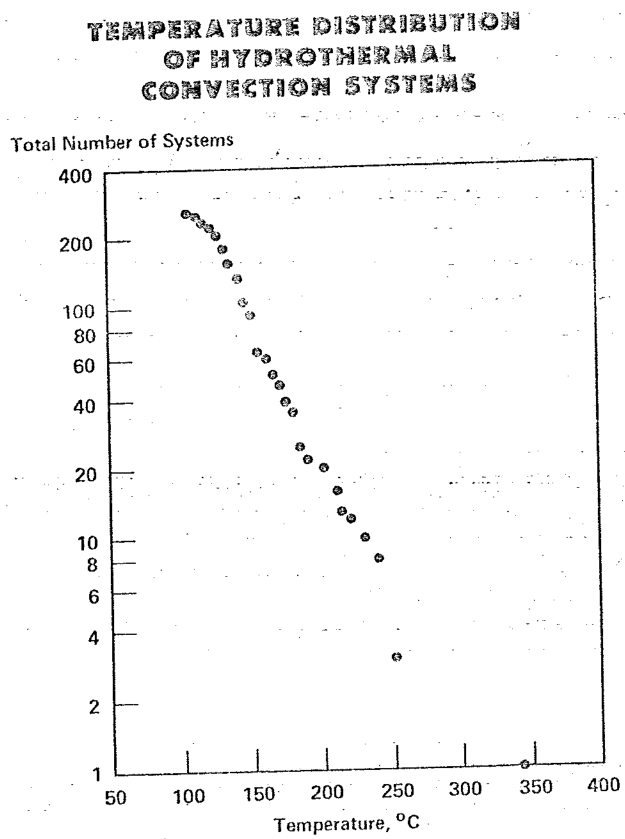

Figure 6

The linear relationship for temperature distribution versus numbers of geothermal systems observed gives us an important technique to estimate the numbers of hydrothermal convection systems each temperature range in the Western U.S. The assumptions in the discussion that follows are:

1) That the observed relationship represents the temperature distribution of the hydrothermal convection systems.

2) That this relationship will hold as additional systems are discovered.

The validity of these assumptions is based on the observed fit between the 257 systems as a large enough sample to represent the true relationship and the fact that a similar relationship exists for the four times as many systems reported in Waring.

At this time no method exists of uniquely determining the distribution so we can only discuss possible levels. There are several lines of reasoning that can be used to suggest 400°C as the upper limit for large scale hydrothermal convection systems. This has been used to provide a broad upper limit of <400°C to the estimated distribution in this paper but is not meant to be a definitive statement on what that upper limit is.

Figure 7 lists the distribution of the calculated curve versus temperature ranges relevant to utilization technology. Also listed is the observed data from Circular 726. This table scales the numbers of systems that can be estimated for each temperature range when the total numbers of systems are 2x and 5x the calculated curve. If the actual numbers of geothermal systems is near the calculated distribution we see that approximately 2/3 of the systems capable of both electric and high temperature non-electric utilization have been discovered. This could have significance to the U.S. geothermal exploration effort. If the distribution is this, the potential for development of hydrothermal convective geothermal systems beyond what has been reported in Circular 726 may be limited.

HYDROTHERMAL CONVECTION SYSTEMS

	USGS	1X	2X	5X
ELECTRIC UTILIZATION				
T >210°C	14	18	36	90
T 150°C-210°C	52	82	164	410
NON-ELECTRIC UTILIZATION				
T 100°C-150°C	196	325	650	1625
T 50°C-100°C	–	1400	2800	7000
Number at 15°C	–	5000	10,000	25,000

Figure 7

If the numbers of systems are 2x to 5x the calculated distribution, significant new opportunities exist for discovery. Obviously, for 2x the known systems only 1/3 of the potential number above 100°C are discovered. Significantly more exist for 5x. These curves are compared in Figure 8. If the scaling factor exceeds 5 the numbers of systems gets quite large. There is, however, the real question of how many high-temperature hydrothermal convection systems of any significant size can exist without surface manifestation? Since the fluids in these systems are derived from metoric waters they have penetrated the earth via fractures. Similar fractures probably exist for the heated less dense fluids to rise to the surface. These fractures can be closed by precipitation from the geothermal brine solutions; they can also be reopened by solution and/or further fracturing processes (e.g., faulting). Over long geologic time these processes may alternate. In any case it seems reasonable to expect many of these systems will have surface manifestations and it may be found that most will. It is for this reason that a scaling factor between 1 and 2 cannot be dismissed until we have more information on "blind" systems in spite of the optimism by those with significant leasing positions. The only "blind" system found to date (the Marysville, Montana anomaly) appears to be limited to a temperature of 100°C which does not qualify it as a high temperature system. It does not appear in the U.S.G.S. estimate but with an estimated energy content of 5.0 (10^{18}) calories becomes the

17th largest geothermal system! Its potential for power production is nil with present and projected utilization technology.

ESTIMATE OF HYDROTHERMAL CONVECTION SYSTEMS

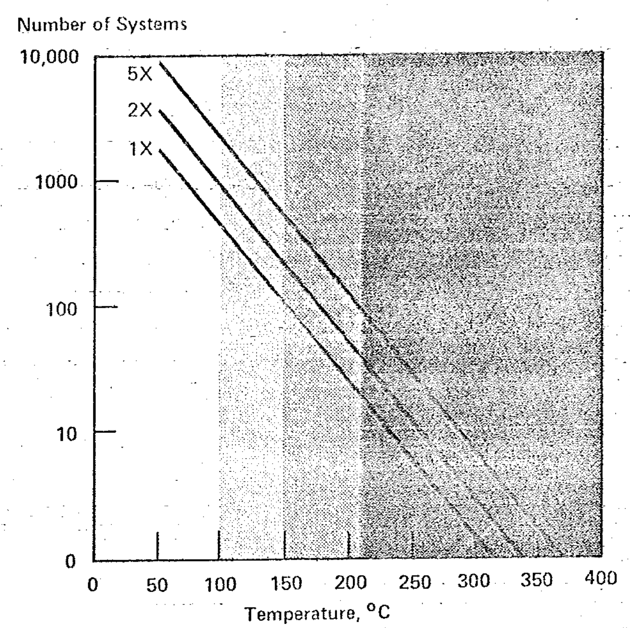

Figure 8

The desired conclusion to this would be a discussion of what the numbers of systems as a function of temperature means to electric power production from hydrothermal convective systems. This is not possible with the available data. The U.S.G.S. has estimated the reserves and paramarginal resources from the known high temperature systems to be about 23,000 MWe for 30 years and perhaps 75,000 MWe still to be discovered. This estimate contained carefully documented assumptions on costs, recovery, price, etc. and appears to be as good an estimate as can be made with the available data.

We can however make some conclusions about the size of the resource:

1) There is not likely to exist thousands of systems capable of electric production using presently available technology, i.e., > 150°C.

2) It looks like only a few hundred systems exist.

3) A conservative estimate of about 100 systems cannot be ruled out.

The previous discussion is important because it allows us to examine the effects of possible numbers of the hydrothermal convective systems. That will determine the long term potential of this least abundant of geothermal resources. The immediate growth in utilization will be dependent on the development of known hydrothermal resources.

This will in turn be dependent on the state of development of utilization technology.

Growth in Utilization

Utilization technology for the vapor dominated systems appears to be well in hand at three widely spaced locations throughout the world, including the U.S. Geysers field which is the world's largest. Certain problems of environmental control exist but these appear to be being worked out at existing plants. Flashed steam plants are in operation in eight different locations in the world. Several candidate systems are known to exist in the U.S.; the reason that none have been developed is not exactly certain. It seems likely that a combination of perceived or real risks and institutional factors have combined to deter the development of flashed steam systems in the U.S. The current best estimate for utilization of this technology in the U.S. is in the early 1980s.

The binary cycle appears to be the preferred method of utilization for electrical generation from geothermal systems whose temperatures are between 150°C and about 210°C. As the temperature decreases, the amount of steam that flashes decreases significantly. The binary cycle uses a liquid with a boiling point lower than water as the working fluid thus permitting operation at lower temperatures. A .75 MWe geothermal binary plant is reported to be in operation in Siberia. A 3.8 MWe binary plant is in operation in Japan using xylene as the heat supplying fluid. The technology of heat exchangers for use with high brine concentrations is developed for the chemical process industry. Thus, all the elements of the binary plant appear to be operable, however no large scale binary geothermal plant has yet been operated. It appears that the binary cycle will be demonstrated in the U.S. by the early 1980s as a result of the EPRI or ERDA programs.

EPRI is in the first stages of a feasibility study to evaluate the potential of two areas for a possible full scale hydrothermal demonstration plant. One of the reservoirs under consideration, Heber, California has a temperature between 150°C and 210°C and the binary cycle is under serious consideration as the method of utilization. Should the decision be made to go with a binary plant at Heber, the binary cycle could be in operation in the United States as early as 1980.

I have attempted to estimate the near term growth in the production of electricity from geothermal energy. Figure 9 lists the estimates for 1985 by area. These estimates were made using published information and when possible the information has been compared with knowledgeable estimates by industry people. The estimates that could be checked do not differ significantly from those given; thus the total should be reasonably accurate.

For the Geysers, the only vapor system, 1800 MWe in 1985 is the estimate by PG&E filed with the California Public Utilities Commission. The 2130 MWe estimate considers the possibility of another utility developing a plant at the Geysers.

The important point to note in the estimate is the development of water dominated resources. This development assumes a 50 MWe plant at Heber in 1980 to be the first water dominated plant. This is assumed to be successful in the case of the upper limit and this success stimulates rapid implementation of development plans for other water dominated areas. In the case of the lower estimate for Heber for 1985 (150 MWe) problems are found which slow down the rate of development by one year. The supposed problems at Heber and other problems combine to slow other development down at other geothermal areas in the lower estimate case. Figure 10 summarizes this information. It is presented to show the predominate effect of the Geysers and to a lesser extent the Imperial Valley on the projection.

ESTIMATED GEOTHERMAL POWER PRODUCTION

VAPOR DOMINATED	
The Geysers	1800-2130
WATER DOMINATED	
Niland	160-210
Brawley	150-200
Valles Caldera	150-250
Long Valley	110-200
Coso Hot Springs	50-100
Roosevelt	150-250
Heber	150-250
East Mesa	100-150
Cove Fort-Sulphurdale	150-250
Raft River	50-100
TOTAL	*3010-4090*

Figure 9

ESTIMATED GEOTHERMAL POWER PRODUCTION

1985 MWe

THE GEYSERS	1800-2130
IMPERIAL VALLEY	510-810
OTHERS	700-1150
TOTAL	*3010-4090*

Figure 10

Other estimates of potential power production from geothermal energy have been made over the last five years. A compilation of many of these for 1985 is given in Figure 11. The assumptions used and the purposes for these projections were often different and this obviously explains some of the variations. Other important factors causing these differences are the assumed introduction date in utilization of the water dominated systems and the amounts of institutional stimulation geothermal development would receive. The range in estimates of the National Petroleum Council (NPC) in 1971 reflects this.

This figure exhibits several interesting points. There is an envelope of decreasing maximum projection of 1985 power production with increasing time. The minimum or conservate estimate has stayed reasonably constant with time and is essentially the same as proposed in this paper. While there is reason for confidence in this paper's estimate of electric power production from geothermal resources, it is not a certainty. Agreement with past conservative estimates does not increase its reliability. Most of the experts I talked to felt the projections in this paper were not pessimistic and the 4000 MWe probably were optimistic. Therefore, it is possible that the electrical production of geothermal energy will not increase the projected 5-7 times in the next nine years.

GEOTHERMAL POWER PRODUCTION

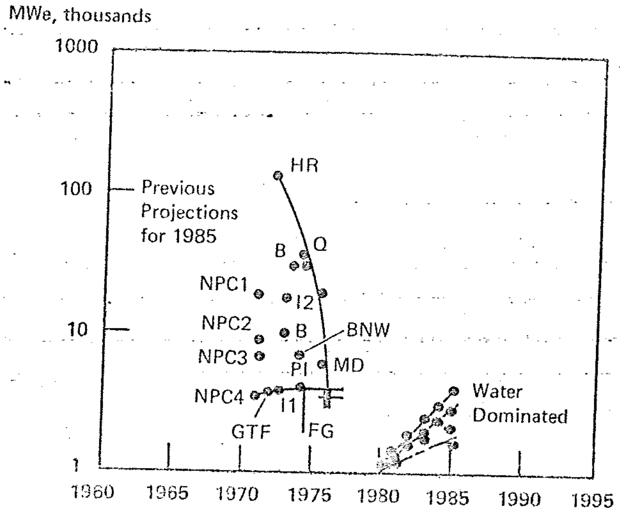

Figure 11

Figure 12 shows the actual and estimated production of electricity with time and contains several important pieces of information. The most and obvious point is that the log MWe versus years plot approximates a straight line over the available information -- both actual and estimated. This is important because the time spans 25 years. With this background hopefully the established trend line can be extrapolated with some confidence for a few years. The trend established shows a factor of 10 increase in geothermal energy production every 10 years! This will essentially be the case in 1985 even if the low estimate of 3000 MWe is what occurs. This implies a doubling time of 3.3 years and is an impressive growth rate. Extrapolation of the curve to 1990 suggests that the potential geothermal power production is 10,000 MWe.

The past estimates of production for 2000 are not plotted as there is little basis for accepting them. An extrapolation of the production curve in Figure 12 would predict 100,000 MWe in 2000. This extrapolation cannot be taken seriously; however, it might indicate an upper limit to the potential for geothermal energy in 2000.

The information shows the progress of an infant industry. Starting from an admittedly small base the geothermal industry has grown quickly and steadily. From the information that is available this fast and steady growth should continue at least another 10 years. This is an achievement -- which the industry can be proud of and should the electric power production be 3500 MWe in 1985 the industry will have lived up to its potential.

This 10x increase in electrical production for geothermal energy cannot obviously continue without new resource or technology developments. The curve indicates that the water dominated systems are needed in the 1980-1990 time frame to continue the trend established early in the development of the vapor systems.

GEOTHERMAL POWER PRODUCTION

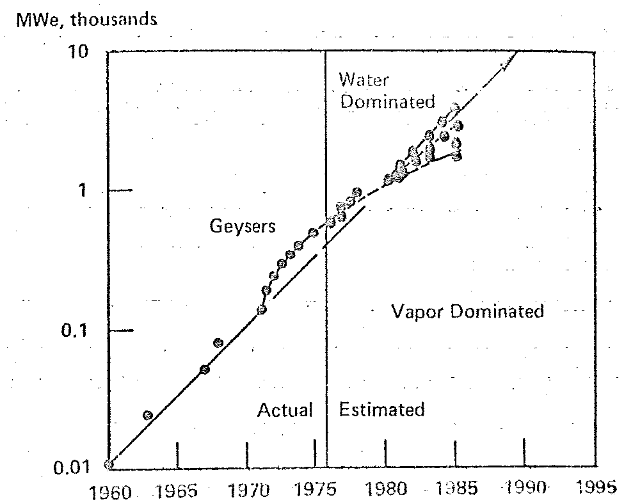

Figure 12

As the available hydrothermal convective systems become developed any attempt to maintain the established growth rate must rely on significant inputs from the hot igneous and geopressure systems. The timing for this appears to be in the early 1990's. This means that the research and development programs for their utilization will have to demonstrate technological feasibility in the late 1980's. Thus the R&D must be done in the next few years.

References

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