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A FORECAST OF GEOTHERMAL DRILLING ACTIVITY*

Gerald L. Brown and A. J. Mansure

The BDM Corporation
1801 Randolph Road, S.E.
Albuquerque, New Mexico 87106

ABSTRACT

This paper specifies the numbers of each type of geothermal well expected to be drilled in the United States for each 5-year period to 2000 A.D. The paper presents forcasts of the growth of geothermally supplied electric power and direct heat uses. The paper then quantifies the different types of geothermal wells needed to support the forecasted capacity, including differentiation of the number of wells to be drilled at each major geothermal resource for electric power production.

The rate of growth of electric capacity at geothermal resource areas is expected to be 15 to 25 percent per year (after an initial critical size is reached) until natural or economic limits are approached. Five resource areas in the United States should grow to significant capacity by the end of the century (The Geysers; Imperial Valley; Valles Caldera, NM; Roosevelt Hot Springs, UT; and northern Nevada). About 3800 geothermal wells are expected to be drilled in support of all electric power projects in the United States between 1981 and 2000 A.D. Half of the wells are expected to be drilled in the Imperial Valley. The Geysers area is expected to retain most of the drilling activity for the next 5 years. By the 1990's, the Imperial Valley is expected to contain most of the drilling activity.

INTRODUCTION

It is of considerable economic importance for both the developer and service companies to have some idea of the magnitude, timing, and location of future drilling activity. The authors have developed a method of expressing drilling activity that is based upon simple relationships between growth of projects and geothermal well characteristics. Empirical evidence (Geothermal Progress Monitor) indicates that electrical capacity from a specific geothermal resource area does not grow at all until some minimum set of favorable criteria are met. Then it grows quickly (15 to 25 percent a year in the cases of The Geysers and Cerro Prieto) until its size reaches some limiting factor(s). The growth potential of electrical capacity at known geothermal resource areas (KGRAs) has been reviewed (Williams et al), and The Geysers/Clear Lake; Imperial Valley, Valles Caldera, Roosevelt Hot Springs, and northern Nevada KGRAs have been identified as the ones expected to meet criteria for significant growth of electrical capacity in this century.

Factors that affect the number of wells that will be drilled to support a given size electric power plant differ among the various geothermal reservoirs (Muffler et al). However, because of similarities in lithology and drilling of the reservoirs in the Imperial Valley, this region has been considered a single resource in this study. The available evidence (Williams et al) indicates that several reservoirs in northern Nevada (especially Steamboat Springs, Beowawe, and Desert Peak) could on a collective basis achieve significant growth before the end of the century. Moreover, only very sketchy data was available on the probable characteristics of the future wells at these resources. Hence, the authors have treated northern Nevada as a single resource area in this paper, despite our recognition of the diverse nature of the individual reservoirs.

Other known resources that were not considered are not expected to achieve significant electrical capacity compared to the ones mentioned above (Ward) because of high development cost (e.g., Raft River), lack of suitable markets (e.g., Puna, Hawaii), or some combination of unfavorable factors (e.g., Coso).

Energy from geopressured and hot dry rock (HDR) resources is either not competitive with coal or nuclear energy or not ready for widespread commercialization, or both. Even if these conditions change and projects using geopressured or HDR resources become competetive or reach critical size for rapid growth in the next 20 years, it is unlikely that drilling activity in these resources will make a significant impact upon the total numbers of geothermal wells to be drilled prior to 2000 A.D. (Brown et al).

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METHODOLOGY FOR ESTIMATING NUMBERS OF WELLS

Geothermal wells are drilled to: a) locate and define new reservoirs, b) provide the production and injection wells required by new plants, and c) replace depleted wells at existing power plants. The number of new wells (a and b above) for a given reservoir will be proportional to the rate of growth of generating capacity (dM/dt) of that reservoir. The number of replacement wells (c above) for a given reservoir will be proportional to the electrical generating capacity on-line (M) at the reservoir.

The number of new wells required will be the growth in capacity (ΔM) divided by the new productivity per well (P) all multiplied by the ratio of the total number of new wells drilled to the number of successful production wells (r), i.e.,

$$\text{New Wells} = \frac{r}{P}\,\Delta M \qquad \text{(Eq. 1)}$$

Estimates of P, the average productivity per well, can be made from actual well tests (well flow rate, temperature, and fluid quality) on individual wells; or the estimates can be based on historical information as to the number of production wells drilled per megawatt of capacity for a typical plant in the field being evaluated. The ratio of total wells drilled to the number of successful production wells, r, must be based on historical data on drilling in the reservoir being evaluated. On the average, the new wells are expected to be drilled about 3 years before the new electrical capacity is due to come on-line.

The number of replacement wells (Brown et al) required will be the capacity on-line (M) divided by the productivity per well (P) times the replacement ratio (R), times the ratio of the total number of new wells drilled to the number of successful production wells (r) or

$$\text{Replacement wells} = \frac{rRM}{P} \qquad \text{(Eq. 2)}$$

R, the replacement value, is determined from historical data on the fraction of wells that must be replaced each year to sustain production. The replacement wells, on the average, are expected to be drilled about one year before they are needed.

In addition to estimates of the coefficients (r, R, and P), estimates of the number of new wells and replacement wells require that generating capacity (M) be forecasted as a function of time. After successful demonstration of power production at a reservoir, the geothermal electrical capacity on-line should grow rapidly until natural, economic, or political limits are approached. Historical growth at The Geysers and at Cerro Prieto (15 to 25 percent per year) typify this growth process. The capacity has been asssumed to grow from an initial critical value (M_0) at a rate initially proportional to the capacity on-line but at a rate that decreases as the maximum resource capacity (M_m) is approached according to

$$\frac{dM}{dt} = \frac{k}{M_m} M\,(M_m - M) \qquad \text{(Eq. 3)}$$

M_0, the initial critical capacity, is estimated from the size of typical geothermal power plants and the development plans of the local utilities. M_m, the maximum resource capacity, is a function of the geology of a reservoir, and can be obtained from Muffler et al or other sources. The solution to the above differential equation for the growth of capacity is

$$M = \frac{M_m}{(M_m/M_o - 1)e^{-kt} + 1} \qquad \text{(Eq. 4)}$$

The constant, k, is evaluated from the initial growth of 20 percent per year and the above differential equation by

$$0.2 = \frac{\Delta M}{M} = \frac{\Delta t}{M_o}\left.\frac{dM}{dt}\right|_{t=o} \quad ;\ \Delta t = 1 \text{ year}$$

or rearranging and substituting into Eq. 3

$$\left.\frac{dM}{dt}\right|_{t=o} = 0.2M_o/\text{year} = \frac{k}{M_m} M_o(M_m - M_o)$$

and solving for k

$$k = \frac{0.2\ M_m/\text{year}}{M_m - M_o} \qquad \text{(Eq. 5)}$$

FORECAST OF WELLS FOR ELECTRICAL GENERATION

The number of megawatts of geothermal electrical power production on-line each year until 2000 A.D., predicted by equation 4, is shown in figure 1 for each of the five significant resource areas identified. Data used to calculate the curves in figure 1 are shown in table 1. Figure 1 shows that for the next 10 years, The Geysers is expected to continue to be the dominant geothermal resource, producing 75 percent or more of the geothermal electric power on-line. In the year 2000 The Geysers and Imperial Valley are expected to have essentially equal amounts of power on-line. For the next 20 years, resources outside California are expected to grow enough to achieve only 20 percent of geothermal power production (Brown et al.).

For The Geysers, Valles Caldera, and Roosevelt Hot Springs, figure 1 shows that the most important factor governing total growth in the next 20 years will be the size of the resource. For the Imperial Valley and northern Nevada resources size will not be a limiting factor in the next 20 years; instead, the growth rate and time when critical minimum size is reached are expected to be the major factors governing total growth of these resources.

TABLE 1. WELL COUNTING PARAMETERS

Resource	Initial Size[1] (M_o)	Growth Starts (t_o)	Productivity[2] (P)	Replacement Rate[3] (R)	Ratio[4] (r)	Maximum Size[1] (M_m)
Geysers/Clear Lake	900	1981	7±3	.044	2±.3	2500
Imperial Valley	200	1986±1	4±1	(.044)[5]	2±.3	7000
Valles Caldera	50	1983±1	3	.033	2	400
Northern Nevada	100	1990±2	(5±1)[5]	(.044)[5]	(2)[5]	1200
Roosevelt H. S.	70	1989±1	5±1	(.044)[5]	(2)[5]	400

[1] MWe

[2] MW_e per production well

[3] The fraction of wells that must be replaced each year

[4] Total wells divided by production wells

[5] Numbers in parentheses are estimates that are not backed by any actual data

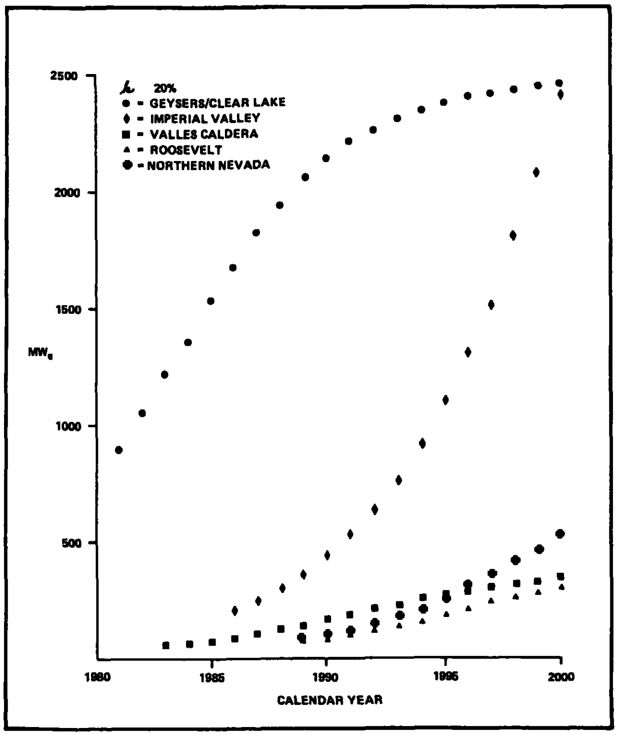

Figure 1. Forecast of Geothermal Electric Power Capacity

Figure 2 shows the number of production, replacement, and other types of wells (injection wells, dry holes, and exploration wells) expected to be drilled in each resource by five year periods. (Figure 2 presents some insights into future drilling activity.) For the next 5 years more than 50 percent of the geothermal wells are expected to be drilled at The Geysers. For the next 20 years there will always be more wells drilled at The Geysers than at Valles Caldera or Roosevelt Hot

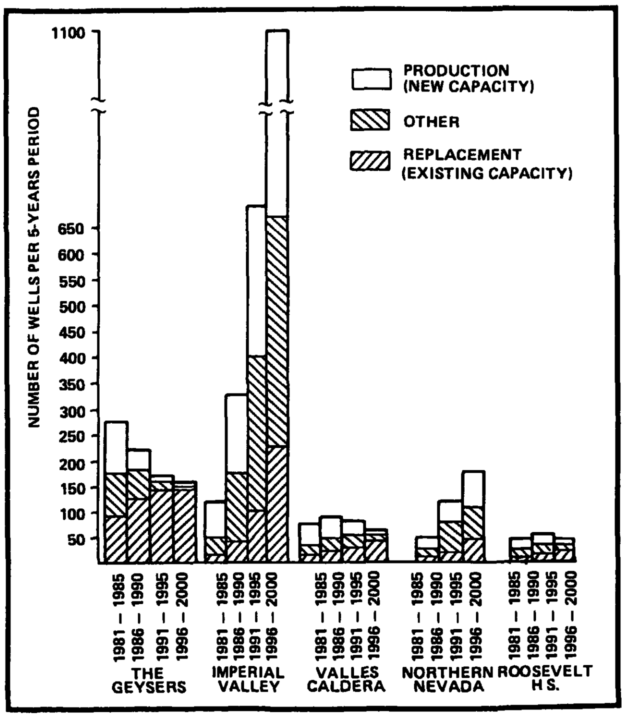

Figure 2. Numbers and Types of Wells to Support the Growth of Geothermal Electric Generating Capacity as Forecasted in Five Resource Areas

Springs, but in about 20 years, the number of wells drilled in The Geysers and Northern Nevada are expected to be about equal. In about 1988 there are expected to be as many wells drilled in the Imperial Valley as at The Geysers. After that time, the Imperial Valley is expected to dominate the geothermal drilling scene to the end of century.

GEOTHERMAL WELLS FOR DIRECT HEAT PROJECTS

The forecast for geothermal direct heat capacity is less certain. Substantial increases in Government aid over the next 10 years might be sufficient to develop the DOE goal of one Quad (10^{15} Btu) per year of geothermal direct heat use by the year 2000. Without such funding the growth of direct heat capacity is likely to be less spectacular. More than a thousand large projects would be needed to meet the DOE goal. The total market for direct heat in the West is about 5 Quads, so that the DOE goal represents a 20 percent share of the market. To meet such a goal, the government would have to provide the fledgling industry with large amounts of aid. Without substantial Government aid, but with a favorable economic climate, direct heat might grow at a rate as high as 14 percent per year. Starting from the present use of 0.001 Quad, this rate of growth would yield a capacity of about 0.02 Quads by the turn of the century. Areas that are expected to dominate the growth of geothermal direct heat capacity over the short term are those locations where geothermal direct heat already exists (such as Klamath Falls, Oregon; Vale, Oregon; Reno, Nevada; and Boise, Idaho).

The beneficial heat derived from direct heat wells can vary greatly. The beneficial heat from a well drilled to heat a single home is about 10^8 Btu/yr, whereas the beneficial heat from a well drilled to support an industrial process often would be more than 1000 times greater. Therefore, the number of wells needed to support 0.02 Quads ranges from several hundred to several tens of thousands depending upon the mix of applications. Based upon the average size of existing uses (Geothermal Progress Monitor), about 6000 wells of all types would be needed to support 0.02 Quads of direct heat use per year. Under this set of assumptions, the number of wells needed to support direct heat is somewhat greater than the number needed to support forecasted electric capacity.

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