# ASSESSMENT OF LOW-TEMPERATURE GEOTHERMAL RESOURCES IN THE UNITED STATES

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## ABSTRACT

A nationwide assessment of geothermal resources < 90°C has recently been completed by the U.S. Geological Survey. Estimates were obtained of accessible resource base, resource, and beneficial heat for 1145 identified low-temperature reservoirs occurring in hydrothermal convection systems and conduction-dominated systems. For identified systems, the nationwide total of thermal energy recoverable at the wellhead (resource) is estimated to be 82 x $10^{18}$ J, from which a total beneficial heat of 39,000 $MW_t$ for 30 years could be obtained.

## INTRODUCTION

Geothermal resource assessment is the estimation of the amount of thermal energy that might be extracted from the Earth and used at costs competitive with other forms of energy at a foreseeable time under reasonable assumptions of technological improvement. The first systematic effort to estimate the geothermal resources of the United States was published in 1975 as U.S. Geological Survey Circular 726 (White and Williams, 1975). This assessment and a followup assessment published in 1979 as Circular 790 (Muffler, 1979) focussed on the quantities of geothermal energy stored in regional conductive environments, igneous-related geothermal systems, hydrothermal convection systems, and geopressured-geothermal systems. Estimates were given of the thermal energy recoverable from hydrothermal convection systems at temperatures of 90°C and above. In addition, the 1979 assessment included a compilation of data on the occurrence of low-temperature geothermal water less than 90°C (Sammel, 1979), but no attempt was made to estimate the associated thermal energy.

Low-temperature geothermal resources occur in two types of geohydrologic environments. These are hydrothermal convection systems, which commonly involve upward flow of thermal water along faults in areas of above-normal heat flow, and conduction-dominated systems in sedimentary basins and coastal embayments, where areally-extensive aquifers occur beneath a thick insulating blanket of rocks having low thermal conductivity. Low-temperature geothermal resources in each of these environments are currently being utilized in space heating, food processing, and other non-electric applications.

To provide estimates of the quantities of thermal energy at temperatures less than 90°C recoverable from geothermal reservoirs in the United States, the U.S. Geological Survey (USGS) recently completed an assessment based on an expanded inventory of low-temperature geothermal occurrences and using a new methodology for estimating recoverable energy. Many state agencies and several private contractors with the support of the State Coupled Geothermal Program of the Department of Energy's Division of Geothermal Energy have provided data for this assessment. Information on water chemistry, temperature, flow rate, and other parameters measured at over 1,000 low-temperature sites has been stored in the computer-based GEOTHERM information system maintained by the USGS. Results of the assessment will be published in a USGS circular in 1982. Additional information for each resource area contained in the GEOTHERM system is available on request.

## METHODS FOR ASSESSING LOW-TEMPERATURE GEOTHERMAL RESOURCES

Assessment of geothermal energy resources involves determinations of the location, extent, and geohydrologic characteristics of each resource area and estimation of the accessible resource base (amount of thermal energy stored in each reservoir) and the resource (the amount of thermal energy that can be produced at the land surface). Identified resource areas are considered to meet the criteria that reservoir permeability is sufficient to supply long-term production and that reservoir temperatures exceed a minimum temperature-depth relation. We used a lower-temperature limit which is 10°C above the local mean annual temperature at the land surface and a 25°C/km temperature gradient with depth. This eliminates assessment of an enormous quantity of shallow groundwater having "normal" temperatures but includes water in reservoirs associated with hydrothermal convection systems and in regional aquifers in many deep sedimentary basins and coastal embayments where temperatures increase relatively rapidly with depth.

The accessible resource base for each low-temperature area identified in this assessment is calculated as:

$$q_R = \rho c \cdot a \cdot d \cdot (t - t_{ref}) \quad (1)$$

where: $q_R$ = accessible resource base (J)
$\rho c$ = volumetric specific heat of rock plus water (2.6 J/cm$^3$°C)
$a$ = reservoir area (km$^2$)
$d$ = reservoir thickness (km)
$t$ = reservoir temperature (°C)
$t_{ref}$ = reference temperature (15°C)

The reference temperature of 15°C is an assumed average mean annual air temperature, and the volumetric specific heat of 2.6 J/cm$^3$°C is a weighted average for rock types found in low-temperature geothermal areas. Statistical methods outlined in Circular 790 were used to quantify the uncertainty in these calculations and to provide probability distributions for the estimates of total accessible resource base, resource, and beneficial heat. For each reservoir, estimates were made of the minimum, maximum, and most likely values for parameters area, thickness, and temperature; these values were then used to form triangular probability densities from which the mean and standard deviation for each parameter and for the various energy quantities were calculated.

Many identified low-temperature areas associated with hydrothermal convection systems are identified only on the basis of a single thermal spring or well because little or no data on subsurface conditions exist. For these areas, a standard reservoir volume of 1.0 km$^3$ was assumed from consideration of possible models of hydrothermal circulation patterns.

The approach used for resource determinations in previous assessments was to assume a recovery factor of 0.25 of the accessible resource base. This factor is based on a heat-sweep process involving injection of cold water into the reservoir to replace hot water withdrawn during production (Nathenson, 1975). In this assessment, resource determination involves estimation of the number of wells each reservoir can support over a development period of 30 years, based on the assumption that cold water will not be injected into the reservoir. Although injection of produced fluids following surface utilization may be legally required in certain areas, lower reservoir temperatures and larger reservoir areas make costly injection schemes for energy recovery less likely to be used in low-temperature geothermal areas than in intermediate- and high-temperature geothermal areas. The method we used to make resource estimates allows for induced recharge of water from permeable regions surrounding each reservoir as reservoir pressures decline. As a result, recovery factors approach 0.25 over 30 years for small-area reservoirs, but are significantly less than 0.25 for large-area reservoirs.

Resource estimates are calculated as:

$$q_{WH} = (\rho c)_f \cdot N \cdot Q \cdot (30\ \text{years}) \cdot (t - t_{ref}) \quad (2)$$

where: $q_{WH}$ = resource (J)
$(\rho c)_f$ = volumetric specific heat of fluid (4.1 J/cm$^3$°C)
$N$ = number of production wells
$Q$ = volumetric discharge rate of each well (L/s)
$t$ = fluid temperature at the wellhead (assumed equal to reservoir temperature) (°C)

A detailed analysis of well-field design for each resource area is not warranted for the purposes of this assessment. Instead, determinations of the optimum number of wells and their spacing were made for an idealized production plan consisting of regularly-spaced wells discharging at 31.5 L/s (500 gpm) for 30 years with a total drawdown at the center of the reservoir of 150 m (500 ft). Based on this production plan, the number of wells which together would produce the specified drawdown is determined by the ratio of reservoir area, a, to the area per well, $a_w$. The area per well is the square of the spacing between wells and is derived from curves presented in the circular that relate well spacing to reservoir area and transmissivity and to leakage properties of confining beds. Methods used to quantify the uncertainty in resource estimates follow those for accessible resource base estimates.

The amount of the resource that can be applied to a specific non-electric utilization is termed beneficial heat. Estimates of beneficial heat from geothermal water can be compared with thermal energy obtainable from other fuels. Selection of appropriate uses for low-temperature geothermal water depends partly on the reservoir temperature, and different applications involve different temperature drops during the heat-exchange process. We have used the following equation, which is based on data for five direct-use applications, to calculate the temperature drop, $\Delta t$, as a function of wellhead temperature:

$$\Delta t = 0.6\ (t - 25°C) \quad (3)$$

Beneficial heat estimates are obtained by substituting $\Delta t$ into equation 2 in place of $(t - t_{ref})$. Units for reporting beneficial heat are megawatts thermal ($MW_t$) for 30 years. For comparison with estimates of accessible resource base and resource, one $MW_t$ for 30 years = 0.945 x $10^{15}$ J. For values of $t \leq 25°C$ the useful $\Delta t$ and the beneficial heat are zero. This limit results from defining low-temperature resources as being at least 10°C above the mean annual land surface temperature, which averages about 15°C across the country.

## ESTIMATES OF RESOURCE BASE, RESOURCE, AND BENEFICIAL HEAT

A total of 1145 low-temperature reservoirs have been identified, exclusive of national parks (table 1). Most of these areas are associated with hydrothermal convection systems in the western United States. In the central United States, resource areas occur primarily in deep sedimentary basins in the Great Plains where regional aquifers contain waters meeting our temperature-depth criterion. In the eastern United States, 25 low-temperature areas in the Appalachian Highlands and Atlantic Coastal Plain have been identified.

The distribution of 1108 low-temperature hydrothermal convection systems as a function of reservoir temperature fits the exponential relation defined in Circular 790 of cumulative frequency versus reservoir temperature for intermediate and high-temperature systems (Brook and others, 1979, figure 11). This relation shows that the number of geothermal reservoirs in hydrothermal convection systems increases exponentially as reservoir temperature decreases.

The total accessible resource base (table 1) is dominated by the thermal energy stored in sedimentary basins in the central United States. However, the methodology for resource calculation yields relatively low recovery factors for this type of resource area. Hence, the total resource estimate, 82 x $10^{18}$ J, is more evenly distributed between the western and central United States. Accessible resource base and resource totals for the eastern United States are relatively small, reflecting in part a lack of exploration activity and in part the widespread existence of low heat flow in rocks of average thermal conductivity.

In identified systems, total beneficial heat is 39,000 $MW_t$ for 30 years, which is equivalent to 37 x $10^{18}$ J. This represents a significant quantity of thermal energy when compared with equivalent requirements for other energy sources (for example, 39,000 $MW_t$ of beneficial heat from a geothermal system is comparable to 39,000 $MW_e$ if that electricity were used to heat a home).

Estimates of the undiscovered low-temperature resources (table 1) in systems whose locations are as yet unknown and in identified systems due to possible upward revisions of reservoir size and temperature are less than corresponding estimates for identified systems. This reflects the degree to which reservoirs meeting our temperature-depth criterion can be delineated at present.

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Table 1. Mean values of geothermal energy from identified and undiscovered reservoirs < 90°C in the United States, exclusive of national parks. (Numbers are rounded off to two significant figures or to three significant figures when the first digit is 1.)

| Type of Geothermal System Region | Number of Reservoirs | Accessible Resource Base ($10^{18}$ J) | Resource ($10^{18}$ J) | Beneficial Heat ($MW_t$ for 30 yr) |
|---|---|---|---|---|
| Hydrothermal Cenvection Systems | | | | |
| Western U.S. | 1048 | 196 | 28 | 12300 |
| Central and Eastern U.S. | 60 | 3.2 | 0.81 | 290 |
| Conduction-dominated Systems | | | | |
| Western U.S. | 9 | 99 | 1.15 | 470 |
| Central and Eastern U.S. | 28 | 24000 | 52 | 26000 |
| Identified Resources | 1145 | 24000 | 82 | 39000 |
| Undiscovered Resources | -- | 7200 | 65 | 30000 |

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