Ministry of Fuel and Power. 1956. *Producer gas for road transport.* July No. 332, London, England.
Nordström, O. 1960. Aktuelle Arbeiten auf dem Gebiet der Ersatztreibstoffe in Schweden D… betrieb, Entwicklung der Holzgas-generatoren und Reinigee. *Motor lastwagen l'autocam…* 000–000.
Nowakowska, J., and R. Wiebe. 1945. *Bibliography on construction, design, economics, per… mance, and theory of portable and small stationary gas producers.* Report No. AIC-103, … Department of Agriculture, Peoria, Illinois.
Porter, J., and R. Wiebe. 1948. *Gasification of agricultural residues.* Report No. ATC-17… Department of Agriculture, Peoria, Illinois.
Producer Gas. 1940. (Date uncertain.) Arrow Press Student Publication No. 4, in collaborat… the Power-Gas Corporation. Watford, Hertfordshire, England: Arrow Press Ltd.
Rambush, N. E. 1923. *Modern Gas Producers.* New York: Van Nostrand Co.
Roberts, R. P. 1938. Producer gas equipment on tractors in Western Australia. *J. Dep. Agr…* *Austr.* 15: 391–402.
SAE Journal. 1940. Swedish gas producer. 46(1): 26.
Science Museum. 1939. *Gas producer for marine engines.* Science Library Bibliography, Ser… 488. London.
Skov, N., and M. Papworth. 1975. *The Pegasus unit.* Olympia, Washington: Pegasus Publish…

alifornia's Geothermal Resource Potential

WIS P. LEIBOWITZ

Abstract Currently the largest geothermal electric generation facility is located in California. The dry-steam resource type being used at the Geysers is economically attractive but its occurrence is quite rare. However, there are indications that large quantities of untapped hydrothermal resources may make the state one of the richest geothermal regions in the world.

Geothermal resources in California have the potential for providing a significant amount of the state's future energy needs. From what is now known, California contains 72% of the currently usable geothermal resources in the United States. By comparison, California's neighboring states have one-tenth of this state's estimated resources. This paper provides an overview of California's geothermal resource areas, estimates of their potential resources, and comparisons with the state's energy consumption. The key factors that currently impede the full-scale exploration and development of geothermal energy are summarized.

troduction

thermal energy is the natural heat of the earth's core that is trapped close ugh to the surface to be extracted economically. Fractures in the earth's crust g the borders of tectonic plates allow heat from the interior to be transported erentially to certain areas near the surface. Areas of geothermal interest in the d are generally associated with these boundaries (see Figure 1). California on top of the junction of the Pacific and American Tectonic Plates, and areas eothermal interest extend along the length of the state in roughly two bands,

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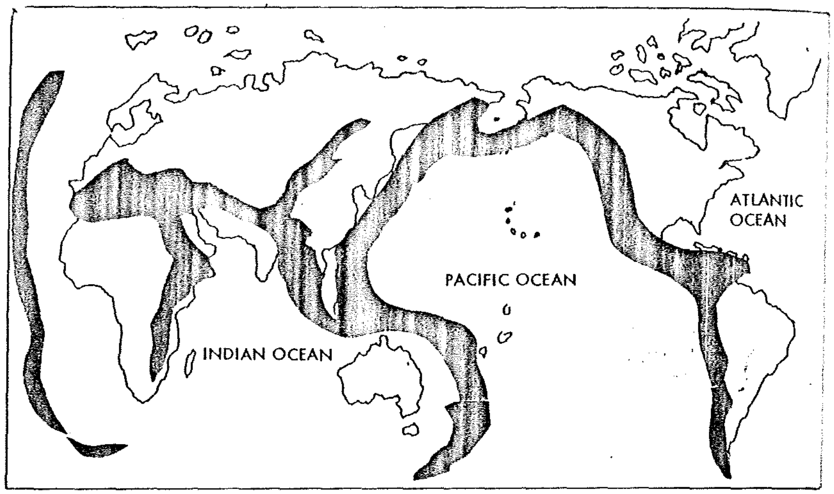

Figure 1. Geothermal areas of the world, based on recent volcanism and crustal-p boundaries.

one along the Eastern Sierra Nevada Mountains and another along the Coa Mountain Ranges (see Figure 2).

Current use of geothermal energy in California has concentrated on the G sers in northern California. Commercial use of this high-quality dry-steam source has been underway for over 15 years. Currently installed electric capa at the Geysers is 502 MWe, which makes it the largest geothermal installatio the world. Utilities have indicated plans to add an additional 1500 MWe capacity by 1985 (Jet Propulsion Laboratory, 1976). Geothermal developm activities are currently high in the Imperial Valley, and the use of this energy both electric power generation and the production of fresh water can be expe early in the 1980s. Exploration and development of other geothermal areas of state have begun.

The energy potential of California's identified hydrothermal systems has cently been estimated by the U.S. Geological Survey to be 19,000 MW produ for 30 yr (White and Williams, 1975). In addition, it is estimated that undis ered hydrothermal systems and the less-developed hot-igneous and conduct dominated systems may greatly increase this potential capacity. The method estimating the state's resource potential and the limitations and uncertainties exist are discussed.

Despite the significant potential of this resource, barriers that prevent the development of this energy source do exist. Concerns over environmental

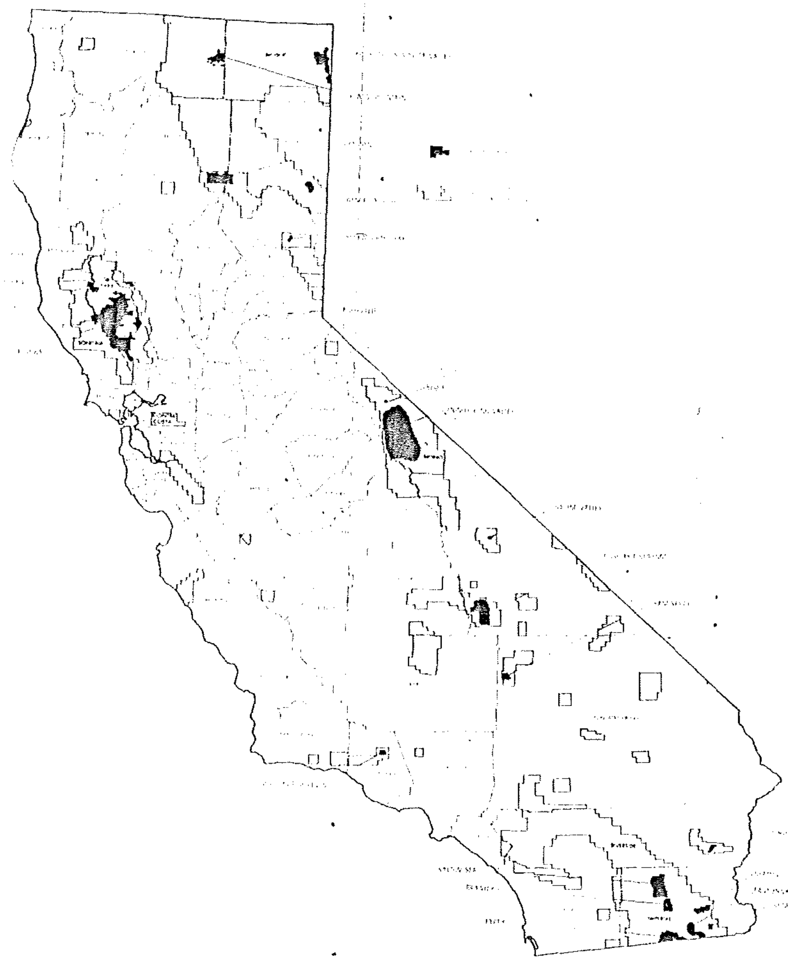

Figure 2. Distribution of KRAs in California.

ts and the development of adequate pollution-abatement techniques have ady caused delays. The ability of private developers to attract risk capital for thermal exploration ventures may be limited. Multiple government agency roval processes slow the development process and may result in higher costs. protection of federal lands from unfavorable environmental impacts may t or prevent development of some resource areas.

alanced concerns for the technical, economic, and environmental factors will quired to permit the potential of this resource to be realized.

Table 1 Heat Content of California's Geothermal Resource Base[a]

Resource type	Energy content (quads[b]) Identified resource	Undiscovered resource
Hydrothermal		
Vapor dominated (steam)	75	75
Liquid dominated (hot water)		
High temperature (>150°C)	650	2000
Intermediate temperature (90–150°C)	30	120
Hot igneous	14,700	55,000
Conduction-dominated		
Near normal gradient	>635,000	0
Geopressured	Unknown	Unknown

[a]Heat in the ground above 15°C without regard to recoverability.
[b]1 quad = 15^{15} Btu and is equivalent to approximately 170 million barrels of oil or 50 million short tons of coal.

Resource Description

Significant quantities of the three types of geothermal resources—hydrother... hot-igneous and conduction-dominated—exist in California. The hot-ign... and conduction-dominated systems may eventually prove to contain the la... amounts of useful energy. However, considerable advancements in techno... are required before these resources can be used economically. Therefore, ... geothermal development interest and activity are presently focused on the ... rothermal resources.

The U.S. Geological Survey recently completed an assessment of the nati... geothermal resources (White and Williams, 1975). The energy content estim... for California's geothermal resources is enormous. A summary of the heat c... tent of California's geothermal resources based on the U.S. Geological Su... data is given in Table 1. The identified[1] high-temperature hydrothermal sy... (i.e., those having temperatures over 150°C) are of particular importance ... state because of their potential for near-term commercial development for ele... power production. As shown in Figure 3, the recoverable energy from Calif...

[1]That is, those geothermal systems tabulated in White and Williams (1975) with identified ... and estimates of reservoir temperature and heat content.

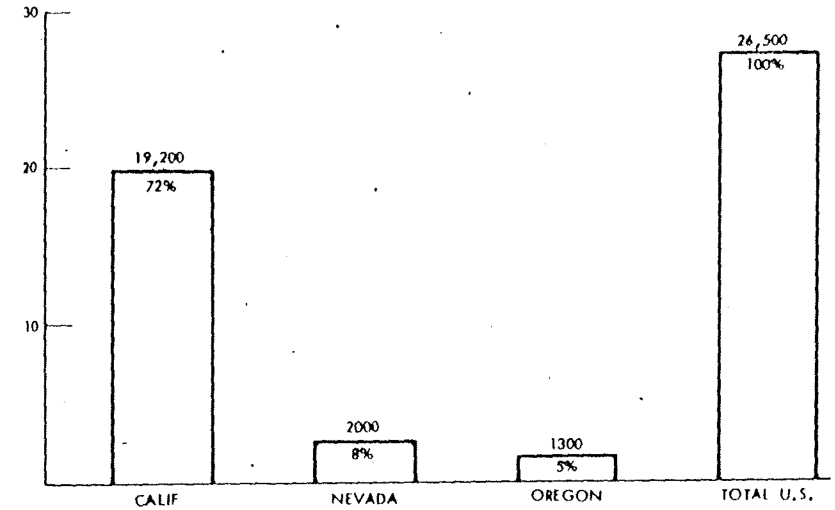

Figure 3. Estimated electric energy potential of identified hydrothermal resources.

...tems is over 70% of the identified U.S. potential for this resource type and ...ghly ten times that of Nevada and Oregon, the states with the next largest ...ntified resources.

There are, however, large uncertainties in the U.S. Geological Survey assess...nt. With exception of the Geysers and some of the fields of the Imperial ...lley, little of the deep drilling necessary to confirm the existence and extent of ...thermal reservoirs has occurred. Most of the data on the wells that have been ...led is proprietary and could not be used to support the energy estimates. As a ...lt, the U.S. Geological Survey assessment of the hydrothermal systems was ...d in large part on extrapolations of surface and near-surface measurements ...f geological manifestations. Further research and exploration data are required ...erify the accuracy of these estimates. The estimates of the energy content of ...e hot-igneous and conduction-dominated systems are even more speculative. A discussion of the different resource types, their locations in the state, and ...mates of their energy content are presented in the following section.

...drothermal Systems

...othermal systems consist of high-temperature steam or hot water stored in a ...me of porous, permeable reservoir rock. Heat is transferred from deep in the ...'s crust by the convective circulation of the steam or water through faults ... fractures in the reservoir rock. This steam or water also provides the vehicle

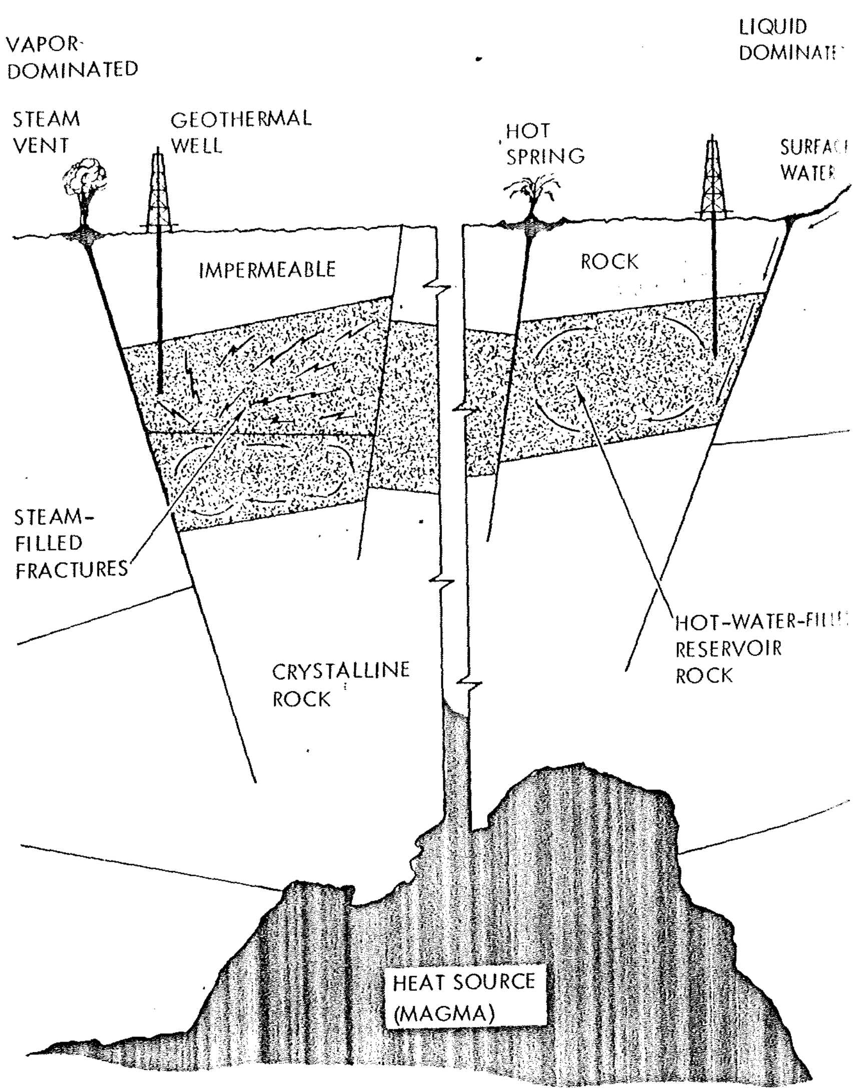

Figure 4. Generalized schematic diagram of a hydrothermal reservoir.

which the stored heat of the reservoir rock can be extracted and brought to the rface (Figure 4). Geothermal reservoirs containing only steam (the Geysers, r example), are referred to as vapor dominated whereas hot-water reservoirs ch as those typical of the Imperial Valley) are referred to as liquid dominated. eas of geothermal interest are usually associated with hot springs, show ologic evidence of recent volcanic activity, and exhibit a high level of conduce heat flow, frequent seismic activity, and occasionally steam geysers or maroles. Throughout the world, liquid-dominated sites are much more numers than vapor-dominated sites (Kruger and Otte, 1973).

he present centers of hydrothermal development interest in the state are in d around "Known Geothermal Resource Areas" (KGRAs). A KGRA is ded in the federal rules and regulations implementing the Geothermal Steam t of 1970 (PL 91-581) (U.S. Geological Survey, 1975). An area may be fined as a KGRA on the basis of geologic and geophysical data or on the basis competitive interests on the part of developers. There are currently 23 such signated areas in the state (Figure 2). For the purposes of this article, the GRAs have been grouped somewhat arbitrarily into five resource regions: the ysers, Imperial Valley, Eastern Sierra, Northeast, and Central Coast. The GRAs included in each resource region and their potentials are given in Table

Exploration for hydrothermal resources is a venture with considerable risk. A ical exploration procedure may consist of the following steps (aside from aining government permits and approval):

Examination of hot springs and surface features
Geochemical survey
Geophysical survey
Heat flow measurements in shallow drill holes
Deep drilling and flow testing of wells

e last step is the only conclusive means, at present, of locating a viable thermal resource. Currently geothermal exploration wells may cost in excess $1 million and success rates for wildcat wells may be less than 10%. When a ervoir has been tapped, a series of additional wells (step-out wells) are drilled d flow tested to determine the extent and capacity of the reservoir. The deci- n to utilize the resource, for example to build an electric plant, is only made er detailed analysis of these tests indicates that an economic resource exists.

mated Potential of Identified Hydrothermal Resources

e U.S. Geological Survey assessment identifies 62 hydrothermal systems in fornia. An identified geothermal site may range from a commercial geother-

Table 2 Estimated Potential of Identified Geothermal Resource Areas

Location/KRGA	*Circular 726 designation*[a]	*Estimated reservoir temperature (°C)*	*Total reservoir heat content (quads)*
The Geysers Region			
Geysers-Calistoga	The Geysers	240	75
	Calistoga	160	3
	Sulphur Bank Mine	185	2
	Skagg's Hot Spring[b]	155	1
	Wilbur Hot Spring[b]	135	10
Knoxville	One Shot Mining	150	1
Little Horse Mtn.	Crabtree Hot Spg.	150	1
Lovelady Ridge	Cook Springs	140	1
Witter Springs	Saratoga Springs	140	1
			95
Imperial Valley Region			
Brawley	Brawley	200	12
Dunes	Dunes	135	2
East Mesa	East Mesa	180	22
	Border	160	1
Ford Dry Lake	d		
Glamis	Glamis (East)	135	2
Heber	Heber	190	44
Salton Sea	Salton Sea	340	83
	Pilger Estate H. S.	145	1
			167
Eastern Sierra Region			
Bodie	d		
Coso Hot Springs	Coso Hot Springs	220	163
Mono Long Valley	Long Valley	220	218
	Near Black Point	125	1
	Paoha Island	125	1
	Red's Meadow	165	1
Randsburg	Randsburg	125	2
Saline Valley	b		386
Northeast Region			
Backwourth Peak	b		
Glass Mountain	b		
Lake City-Surprise Valley	Surprise Valley	175	95
Lassen	Morgan Springs	210	5
Wendel-Amedee	Wendel-Amedee	140	5
			105
Central Coast Region			
Sespe Hot Springs	Sespe Hot Springs	155	1

[a]See White and Williams (1975).
[b]Outside of KGRA boundaries.
[c]Temperature too low for commercial-power generation but may be valuable for nonelectrical ap...
[d]No data available.

...al field to a hot spring with favorable geochemical measurements. Most iden-...ed sites are the result of the surface manifestation phase of exploration. Only a ...s sites having no surface manifestations have been identified by geophysical ...ploration and drilling. Of the identified sites, 16 have estimated temperatures ...ove 150°C and 46 have estimated temperatures ranging from 90 to 150°C. ...se systems above 150°C may be suitable for electric power production, ...ereas those of lower temperature may be important in nonelectrical applica-...ns. Figure 5 shows the locations of these identified systems throughout the ...te.

The U.S. Geological Survey estimated the energy potential of each identified ...-water system using the process diagrammed in Figure 6. Reservoir tempera-...e estimates were based primarily on geochemical analysis of surface waters ...n springs or shallow wells. Reservoir areas were estimated from all available ...a, which included surface manifestations and geology and, where available, ...physical data. The maximum reservoir depth was arbitrarily assumed to be 3 ... (1.86 mi), the current maximum depth of geothermal drilling. The top of the ...ervoir was generally assumed to have an average depth of 1, 1.5, or 2 km ...62, 0.93, or 1.24 mi), depending on the assumed shape of the convection ...stem and the inferred similarities to drilled areas. The volumetric specific heat

TEMPERATURES ABOVE 150°C — TEMPERATURES 90 – 150°C

...ure 5. California's identified hydrothermal systems (after White and Williams, ...).

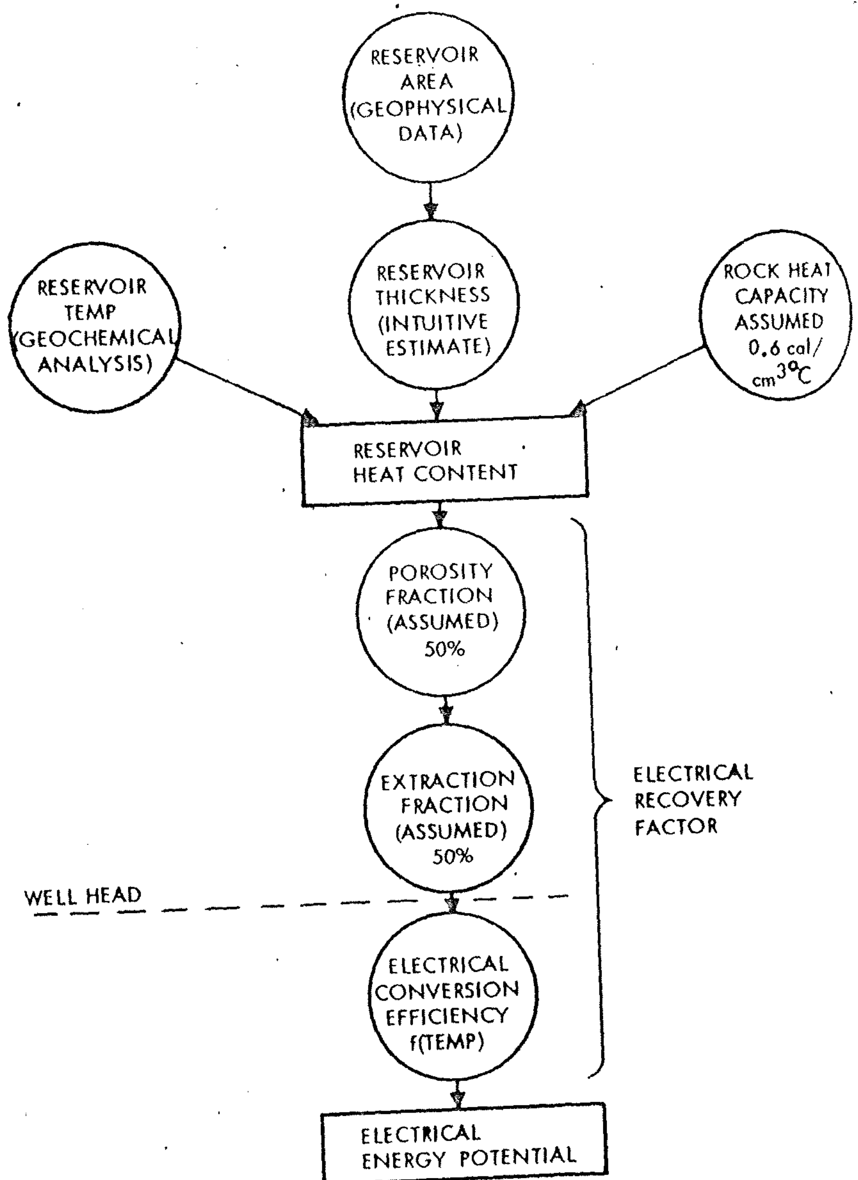

Figure 6. Schematic diagram of the U.S. Geological Survey hydrothermal energy assessment process.

of the rock was assumed to be 0.6 cal/cm³. These factors established the estimated heat content of the reservoirs (systems). The U.S. Geological Survey then estimated the recoverable electric energy potential of those identified systems with temperatures in excess of 150°C. The estimation of the recovery factors generally involved three steps:

1. An estimation of what part of the hydrothermal system is porous and permeable rock (assumed 50%)
2. An estimation of the fraction of the stored heat in the porous and permeable volume that can be recovered at the surface (assumed 50%)
3. A calculation of the efficiency with which thermal energy at the wellhead can be converted to electric energy in a power plant (varied as a function of temperature)

The estimated recovery factors for hot-water systems ranged from 2% for temperatures of 150–200°C to 3% for temperatures of 250–300°C. They were even less for vapor-dominated systems. The result of this analysis was an estimate of total useful energy that could be produced from a geothermal reservoir. A more detailed approach would require consideration of well flow rates, reservoir size, and lifetime. Since these data do not exist for most resource areas, the simplified recovery analysis permits a consistent evaluation of the state's identified resources.

The distribution of identified resource potential within the current KGRAs is shown in Table 2. Eighteen of the 23 KGRAs are associated with identified hydrothermal systems. The potential for electric energy production has been estimated for identified sites at nine KGRAs in the state (see Table 3). The distribution of this electric potential in the five resource regions is shown in Figure 7. The estimated potential of the Eastern Sierra and the Imperial Valley regions is larger than that of the Geysers region. The estimated resources of the Mono-Long Valley and Coso Hot Springs KGRAs are particularly large.

Regional Hydrothermal Resource Knowledge

More is known about the resources in the Geysers region than about those in the other regions of the state. The Geysers steam field is responsible for most of the geothermal production in California and is the only producing steam field in the United States. Knowledge of the reservoir production characteristics, temperatures, and resource boundaries results from the drilling of over 150 wells[2] in the area. However, the resource boundaries are still known only approximately and

[2] From records of the California Division of Oil and Gas, Sacramento, California.

Table 3 California KGRAs with Identified Electric Energy Potential

KGRA	*Electric energy potential (MWe for 30 yr)*
1. Mono-Long Valley	6,083
2. Coso Hot Springs	4,533
3. Salton Sea	2,786
4. Lake City-Surprise Valley	2,123
5. Geysers-Calistoga	1,723
6. Heber	973
7. East Mesa	487
8. Brawley	333
9. Lassen	133
	19,174

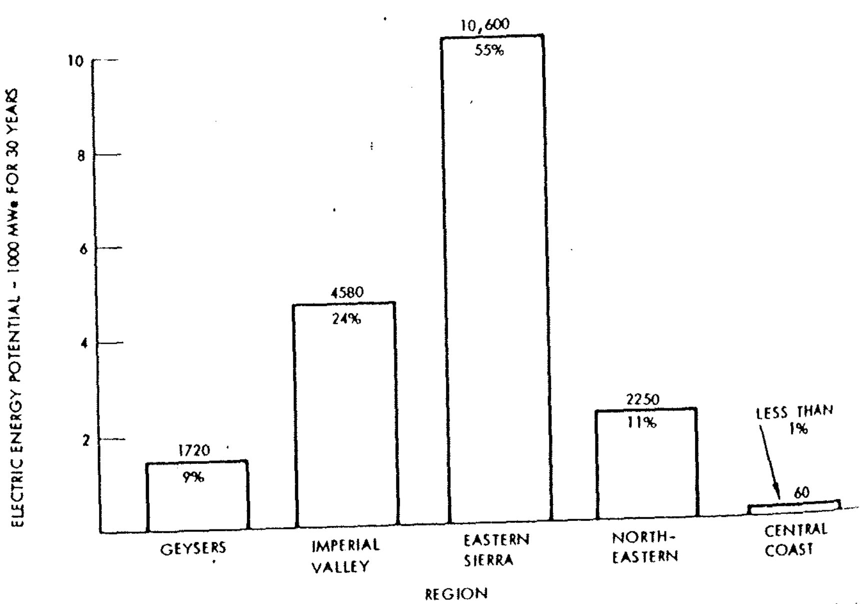

Figure 7. Estimated electric energy potential by region of California's identified hydrothermal resources.

exploration efforts are extending many miles from the production wells. The ultimate capacity of this region depends on how successful the efforts are to discover extensions to the identified reservoirs.

Knowledge of the Imperial Valley region's geothermal resources approaches that of the Geyser's region. This region has been the subject of extensive geophysical surveys which have helped to define the identified resource areas. Deep drilling has now occurred at the majority of the resource sites in the region (Brawley, Dunes, East Mesa, Heber, and Salton Sea). The data on the wells at Brawley, Heber, and the Salton Sea are proprietary. However, two independent assessments (S. Biehler, personal communication, 1976; Towse, 1975) of the energy potential of the region are in reasonable agreement with those of the U.S. Geological Survey.

The Eastern Sierra region is unique in that, although it potentially contains the largest resources in the state, there has been very little exploratory drilling. The two major resources in the region are in the Mono-Long Valley and Coso Hot Springs areas. Estimates of the potential for Mono-Long Valley indicate a resource larger than the total Imperial Valley region. These estimates are based on the results of an extensive U.S. Geological Survey, geophysical and geological survey of the Long Valley area (Muffler and Williams, 1976). The outline of the collapsed structure of a volcano (caldera) covering over 350 km^2 (135 mi^2) surrounds the area of the possible reservoir. Interpretation of geophysical surveys indicates that a reservoir of 225 km^2 (87 mi^2) underlies the caldera.

The Coso Hot Springs KGRA in the Eastern Sierra region is estimated to have a resource potential roughly equal to that of the Imperial Valley region. There has been no deep-drilling activity in the resource areas, and estimates are based only on surface manifestations and geophysical surveys. However, geophysical exploration of this resource has not been as detailed or covered as much area as that in Long Valley. Duffield (1975) has recently found an oval-shaped ring of faults covering 1500 km^2 (580 mi^2) and surrounding the area of hot springs. This ring structure suggests a large underlying magma chamber. However, on the basis of the limited area covered by geophysical surveys in the region to date, the U.S. Geological Survey estimates a reservoir covering 168 km^2 (65 mi^2) or approximately one-tenth the area indicated by the ring structure. Further surveys by the U.S. Geological Survey and the Energy Research and Development Administration (ERDA) and deep drilling will provide a more precise picture of this resource.

Exploration data on the resources of the Northeast and Central Coast regions are limited. Drilling has occurred primarily in the Lake City–Surprise Valley and Wendel–Amedee areas. Fewer data are available on the potential of the other KGRAs in these regions.

Estimation Uncertainties

The process used to estimate the potential of the identified resources in California is subject to large uncertainties. The temperatures used for most resources were estimated with geochemical analysis of SiO_2 and Na-K-Ca ratios of surface water samples. This analysis process gives the minimum value of the reservoir temperature, as was indicated by the U.S. Geological Survey report. This tendency to underestimate temperature is supported by the results of a recent summary of exploration experience (McNitt, 1975), which presented a comparison of geothermometer data and actual reservoir data. Temperature is a particularly critical parameter in electric power generation. Water flashed from 300°C to a separator yields 33% steam; 200°C yields 11%; and 150°C yields none (White and Williams, 1975). Thus the estimated electric energy potential of the identified systems could be low as a result of underestimation of reservoir temperatures. (This may be mitigated somewhat by the relatively low value, 150°C, used for minimum reservoir temperature for electric energy production.) The estimates of reservoir area were felt to contain possibly the largest uncertainties (White and Williams, 1975). Order of magnitude errors in area estimates are possible. The calculation of recoverable energy made the assumption that 25% of the heat content of the reservoir could be extracted (i.e., brought to the wellhead). The actual value of this parameter can vary greatly from reservoir to reservoir and from well to well.

Many of the identified systems are listed with small heat contents (less than 4 quads). These resources should not necessarily be considered insignificant. In many cases the small estimate is the result of very limited knowledge about the subsurface features of the resource. These estimates are based primarily on the area covered by surface manifestations, which may have little relationship to the actual size of the reservoir. Investigations need to be performed at these sites before better estimates of their potential can be made.

Undiscovered Hydrothermal Resource Potential

The hydrothermal resource estimates that have been described are restricted to the evaluation of currently identified sites of geothermal potential. In addition, this resource potential may be significantly increased by currently undiscovered reservoirs. The U.S. Geological Survey estimates that future discoveries may locate three to five times the currently identified resources. These increases could result from the discovery of previously unknown systems; new knowledge of the extent of an already identified system; and the discovery of a high-temperature system at a resource location considered to be of low quality.

Hot-Igneous Systems

The hot-igneous (volcanic) systems occur in regions where molten magma generated deep in the earth's crust or mantle has risen upward through narrow pipes and fissures to form magma chambers in the shallow crust. Unlike the hydrothermal resources, these magma chambers do not have a fluid circulation system to bring the heat to the earth's surface. The hot-igneous category consists of systems still partly molten, with temperatures in excess of 650°C, and hot dry rock systems where the magma is no longer molten (i.e., less than 650°C) but still very hot. The U.S. Geological Survey (Jet Propulsion Laboratory, 1976, p. 77, Figure 5) has identified 17 such silicia volcanic systems in California (Figure

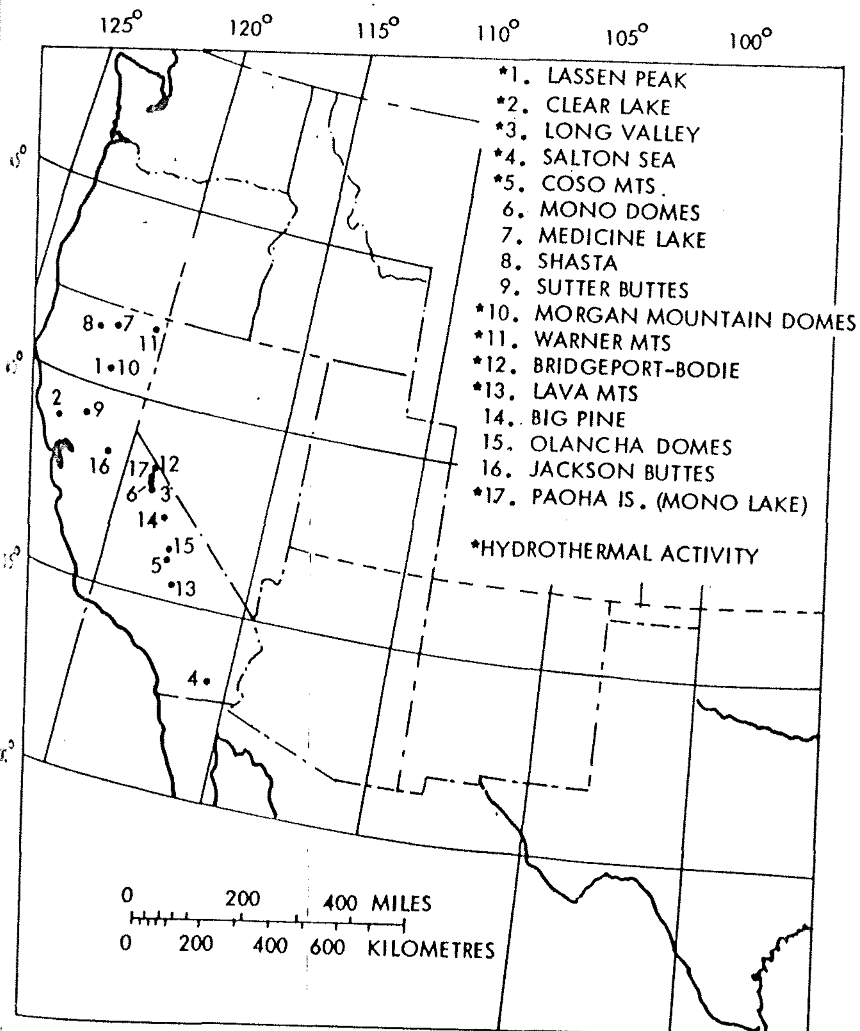

Figure 8. California's identified volcanic systems (after White and Williams, 1975).

8). The heat content of the ten systems for which some data exist was estimated by the U.S. Geological Survey to be roughly 14,700 quads (Jet Propulsion Laboratory, 1976, pp. 68–69, Table 7). This is almost 20 times that estimated for identified hydrothermal systems. These estimates are very speculative since the data available on these systems are limited.

The heat in the molten parts of magmatic systems is not recoverable with current technology. The tops of the inferred magma bodies lie at estimated depths that are all greater than 3 km (1.86 mi). Because of the depths and the high temperatures involved (650–1200°C), technology problems are formidable. Much heat is also stored on the margins of the molten systems and in the now-solidified systems (i.e., temperatures less than 650°C). These systems constitute favorable targets for recovering heat energy by using hydraulic fractures to produce circulation loops in a body of low-permeability rock. This is the purpose of the hot dry rock project under ERDA sponsorship (Smith et al., 1975). Although the results to date on this project are encouraging, many problems still have to be solved before the hot dry rock concept is proved. Therefore, the economic extraction of energy from this resource remains in the future.

Conduction-Dominated and Geopressured Systems

Conduction-dominated heat flow constitutes by far the largest part of the resource base (see Table 1). Most of the heat is transferred from deep within the earth by thermal conduction through solid rock. Some heat is generated by normal radioactivity of rocks in the upper crust. The volume of rock involved is large but the average temperatures are low. The heat content in California is estimated to exceed 635,000 quads (White and Williams, 1975). The basin and range provinces typical of parts of California and the West have the highest temperature gradients. Although this resource is large, the extraction of energy from these systems requires very deep wells, in the range of 5–10 km (15,000–30,000 ft) in order to obtain temperatures of greater than 100°C. Therefore utilization of these resources is not now economical. Low-grade hydrothermal resources, which have seen very little development, represent a much more attractive resource at the present time.

The geopressured geothermal resource represents a special category of the resource. Geopressured resources consist of zones of hot water, highly pressurized by the weight of the overlying geological formation. Large areas of this resource have been identified in the Gulf Coast states. Energy is stored in this resource in the form of thermal energy, hydraulic energy of the high pressure fluid, and combustion energy of dissolved natural gas. Studies of high fluid pressure regions of California by F. A. Berry (1973) indicate that an extensive zone of high pressure fluid 40–130 km (25–80 mi) wide and 650–800 km (400–

500 mi) long extends along the east side of the San Andreas fault. Temperatures associated with this region are, however, not of geothermal interest. A possible exception to this may occur in the southern San Joaquin Valley, where temperatures may exceed 100°C. However, few data are available on the extent of this resource.

Impediments to Development

The large-scale development of geothermal energy depends not only on the accuracy of the resource estimates but on technical, economic, legal and institutional factors as well. Some of the impediments to the exploration and utilization of geothermal resources are briefly summarized below. A more detailed description of these issues may be found in Batelle Memorial Institute (1976) and Jet Propulsion Laboratory (1975, 1976).

Technology Development. The development and demonstration of economic means of utilizing liquid-dominated resources is required. Technology for handling highly corrosive brines at the Salton Sea is required before this sizable resource area can be used. Technology for the economic utilization of moderate temperature resources must be demonstrated before the many resource sites in this category can be considered as targets for commercial development. The eventual use of hot-igneous and conduction-dominated systems depends on the successful outcome of research efforts to tap these resources.

Environmental Concerns. By comparison with conventional energy supplies, environmental impacts of geothermal energy may be small. Nonetheless, concerns over air pollution (primarily H_2S), water pollution, noise, and wildlife habitat destruction may limit geothermal development. The development and acceptance of effective abatement techniques may minimize this factor.

Land Use Conflicts. The exploration and development of geothermal resource sites may conflict with existing land uses in the vicinity of the site. In the Geysers and Eastern Sierra regions, recreation and retirement needs may conflict with resource development. In the Imperial Valley agricultural land use may have an impact on geothermal development.

The leasing and environmental assessment of federal lands for geothermal development is required for widespread development of the Eastern Sierra and Northeast areas.

Cooling Water Availability. The installation of large numbers of geothermal generating plants requiring cooling water will have an impact on the water supply of an area. In areas of limited water supply (i.e., the Eastern Sierra and Imperi Valley regions) geothermal development may proceed only to a level for whic water supplies can be available.

Commercial Interest. Large quantities of capital must be placed at risk in orde to explore and develop geothermal resources. In order for sufficient explorati capital to be made available, geothermal energy must appear attractive compare with other investment opportunities. Commitment of traditionally risk-aver electric utilities to geothermal plant construction requires confidence in both th economic viability of the utilization process and in the lifetime of the geotherm reservoir. Assurance, based on reservoir analysis, that reservoir lifetime is suff cient to permit the plant investment to be fully amortized (typically 30 yr) i required.

Conclusions

As an energy resource, geothermal resources can have a significant impact o California's energy supply. In terms of stored heat, identified hydrotherm resources have been estimated to have an energy content of 750 quads. H igneous and conduction-dominated resources may have a heat content hundre of times greater than hydrothermal resources. By comparison the total energy u for all purposes by the state of California in 1975 was approximately 6 qua (California Energy Resources Conservation and Development Commissi 1975).

Physical, technical, and economic factors will permit only a fraction of th in situ geothermal heat content to be extracted and used. The high-temperatu hydrothermal resources have the greatest potential for near-term utilization f commercial electric power production. The U.S. Geological Survey estimat that the recoverable thermal energy from currently identified hydrothermal sy tems could be utilized to provide the equivalent of over 19,000 MW of electr power for 30 yr. If the identified geothermal resources of California could b tapped in unison, they could supply the state's electric energy for more than 30 y at the 1975 rate of power consumption (160,000 GW/hr). In addition, furth geothermal exploration will identify new geothermal sites which may have pote tials even greater than those of identified resources.

The resolution of the current impediments to development through technolog development and governmental action will bring a valuable resource to use f the benefit of all concerned.

Acknowledgment

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eferences

elle Memorial Institute. 1976. *Legal, institutional, and political problems in producing electric ower from geothermal resources in California.* Seattle, Washington.

ay, F. A. 1973. *AAPG Bull.* 7:217.

lornia Energy Resources Conservation and Development Commission. 1975. *Quarterly fuel and ergy summary, 1975.*

held, W. A. 1975. *Geology* 3: 335.

Propulsion Laboratory. 1975. *Program definition for the development of geothermal energy.* ocument 5040-6. Pasadena, Calif.

—. 1976. *Report on the status of development of geothermal energy resources in California.* ocument 5040-25. Pasadena, Calif.

ger, P., and C. Otte. 1973. *Geothermal energy.* Stanford, Calif.: Stanford University Press.

itt, J. R. 1975. Summary of United Nations geothermal exploration experience, 1965 to 1975. *Second United Nations symposium on the development and use of geothermal resources.*

ler, L. J. P., and D. L. Williams, 1976. *J. Geophys. Res.* 8: 721.

h, M. C., R. L. Aamodt, R. M. Potter, and D. W. Brown. 1975. Man-made geothermal ervoirs. In *Second United Nations symposium on the development and use of geothermal sources.*

e, D. 1975. *An estimate of the geothermal energy resources in the Salton Trough, California.* wrence Livermore Laboratory Report UCRL-51851.

Geological Survey. 1975. *Geothermal steam act of 1970 and regulations on the leasing of othermal resources.* Washington, D.C.

e, D. F., and D. F. Williams. 1975. *Assessment of geothermal resources of the United States.* 75. U.S. Geological Survey Circular No. 726. Washington, D.C.