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Energy shortage stimulates geothermal exploration

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10-second summary

Geothermal resources are attracting increasing attention as a potentially important contributor to the U.S. energy equation. This article discusses the various types of geothermal deposits, necessary geological conditions, projects now underway, exploration methods used, current activity and the possible impact of this energy source on U.S. requirements.

EXTENSIVE exploration programs now are underway in the western United States to evaluate potential of geothermal energy. A variety of companies are involved in the effort, including many gas and oil producers.

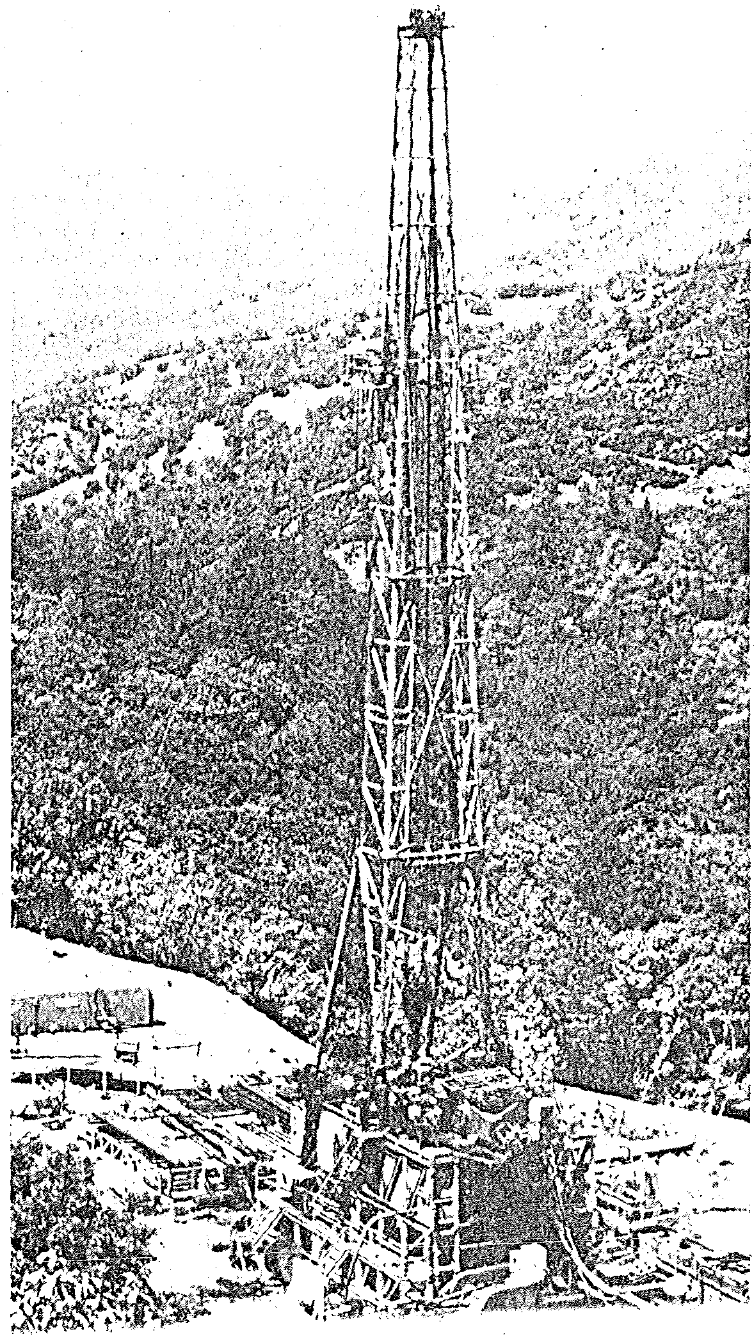
Advantages of geothermal energy as a power source can be demonstrated, and these account for its increasing stature in the energy picture. Environmental impact of electrical power generation using geothermal energy is well below that of other power systems, even though noise, noxious gases and waste water may have to be contended with in the field.

Energy reserves appear to have a long life, although geothermal fields cannot claim to be entirely non-deplet-

EDITOR'S NOTE

Geothermal energy may prove to be an important future U.S. power source. However, extent and potential of geothermal resources in the United States remain virtually unknown, since exploration still is in its infancy and government red tape still precludes investigations in many highly potential areas.

Exploring for and developing geothermal resources involve many of the same techniques and equipment used in finding and exploiting gas and oil reserves. This two-part special report presents latest information on technology used in geothermal operations and points out both advantages and limitations of geothermal energy.



Heavy drilling equipment is required in Geysers field development. This Hoover Drilling Co. rig completing a steam well in the eastern sector of the field is one of three rigs currently active at The Geysers.

Passive seismic equipment used to detect microearthquakes and monitor noise is highly compact, portable and unobstrusive. Recent geothermal discoveries have been based to a large extent upon geophysical data.

ing. Capital and operating costs per unit of generating capacity at the few geothermal fields now operating are significantly below those of fossil fuel and nuclear power plants.

Geology. Temperature generally increases with depth beneath the earth's surface, but in many areas temperature gradients are anomalously high. Regionally, high thermal gradients occur in areas of geologically recent volcanism and tectonic activity. In the United States, such environments are found in the West, especially in seismically active provinces such as the Basin and Range, Sierra Nevada, Coastal Range, and Cascades.

Some criteria significant to the search for geothermal energy are:

- Youthful acidic volcanism, evidenced by cinder cones, lava flows, calderas, and shallow intrusives.

- Contemporary fracturing and fault movements, evidenced by earthquake activity.

- Abnormally high heat flow, either quantitatively measured or qualitatively indicated by hot springs and fumaroles.

- Passage or presence of hydrothermal fluids, evidenced by recent rock alteration.

- Adequate groundwater and favorable conditions for recharge.

- Presence of epithermal and telethermal mineral deposits such as mercury and fluorspar.

In the western United States many of these criteria can be found at the intersection of major deep-seated structural trends and along boundaries of geologic provinces that coincide with crustal discontinuities.

Three main types of geothermal deposits have been recognized. Of prime commercial importance is the vapor-dominated or dry steam type, whose superheated steam can be fed directly to a turbine. Dry steam systems are believed to be rare.

The most common geothermal deposit by a factor of perhaps 20:1 is the hot water system, or combination steam-hot water system. Steam is produced by boiling or flashing as fluid moves to the surface and pressure drops correspondingly. At the surface, this mixture of steam and water must be separated before steam is fed to the turbine. Hot water and steam-hot water systems are economically less attractive as energy sources simply because of the large volumes of water that must be handled to obtain sufficient steam to operate even a moderate size turbine.

The third type of geothermal deposit is the regional or geopressured system, where normal heat flow of the earth is trapped by insulating impermeable clay beds in a rapidly subsiding geosyncline. A prime example of this type of system occurs at depth in the Tertiary Gulf Coast basin of the United States. The enormous size of these low temperature geopressured systems offers a large potential—but still theoretical—future energy source. Currently, cost of production from these deep systems appears to exceed greatly the value of the energy that can be produced.

Geothermal history. The most valuable use of geothermal energy is its conversion to electricity for transmission over long distances. First such use was at Larderello, Italy, in 1904, when an experimental 250-kw plant was installed. This work gradually has evolved into a commercial producing field with current generating capacity of 365.5 megawatts.

No other commercial production of geothermal power occurred until about 1960, when small plants were started in New Zealand and the United States. In 1973, total world capacity of geothermal power from eight countries is just over 1,000 megawatts (Table 1), with another 817 megawatts of capacity expected to be installed by 1977 (Table 2) in existing areas plus six additional countries. By comparison, year-end 1972 total U.S. electrical generating capacity from all power sources was 399,606 megawatts.

The search for new geothermal power sources is currently under way in at least 23 other countries—Algeria, Bulgaria, Chile, Colombia, Czechoslovakia, East Germany, Ecuador, Ethiopia, Fiji, Greece, Guatemala, Hungary, India, Indonesia, Israel, Kenya, Morocco, Nicaragua, Poland, Spain, Tunisia, Venezuela and Yugoslavia.

The Geysers field. The U.S.' only operating geothermal field and the world's largest is located in Sonoma County, California, about 80 miles north of San Francisco. First wells to supply steam for electric generating purposes were drilled at The Geysers in 1921-22. The project was abandoned in 1928, but revived in 1955, when Magma Energy Co. and Thermal Power Co. began a program of drilling and economic evaluation. These investigations resulted in a contract with Pacific Gas & Electric in 1958 to supply geothermal steam for a 12.5-megawatt power plant that went on line in 1960.

This original plant was supplemented by nine other generating plants through mid-1973, with a total present generating capacity of 396 megawatts (Table 1). Steam suppliers are the Magma-Thermal Power Project and Union Oil Co. venture at the present, to be joined by Signal Oil & Gas and Pacific Energy Corp. in the future. Four other plants are under construction, or planned.

By 1975 The Geysers will have power production capacity sufficient to supply the city of San Francisco. Ulti-

TABLE 1—Geothermal fields producing in 1973

Country	Fields	Year commercial production started	1973 capacity megawatts
Italy	Larderello	1912	365
	Monte Amiata	1959	25.5
New Zealand	Wairakei-Broadlands	1960	170
United States	The Geysers	1960	396
Japan	Matsukawa	1966	20
	Otake	1967	13
U.S.S.R.	Pauzhetsk	1967	29
Iceland	Namafjall	1969	3
China	Kwantung Province	1958	?
Mexico	Cerro Prieto	1973	75
			1,059.5

mate potential of The Geysers is estimated to be 1,000-2,000 megawatts. Consulting engineers have appraised future net revenue from one portion of The Geysers at $150,000 per acre over a 15-year period.

Steam comes from a reservoir of highly fractured graywackes, shales and basalts of the Jurassic-Cretaceous Franciscan formation. Heat source is believed to be a buried igneous mass of Pleistocene age a few miles northeast of the field. Wells are completed at depths of 4,000-8,000 feet, producing on an average 150,000 pounds of 570° F steam per hour. Steam production is from northwest-trending shear zones in an area about 5 miles long and 2 miles wide. Recent exploration suggests that the future productive area may be twice as large as the present field.

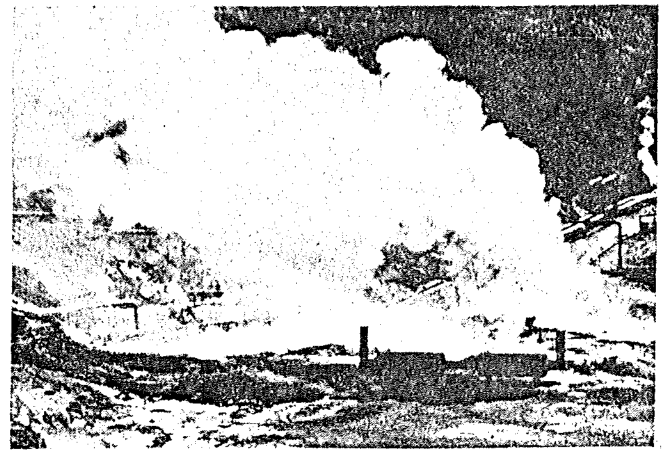
Other areas. The Imperial Valley of California and Mexico may also become a major geothermal province. Several steam-hot water systems have been discovered, one of which now is in production, at Cerro Prieto, Mexico. Numerous companies have holdings in the area, including Magma Energy, Chevron, Union, Arco, Southern Pacific and Phillips. In addition to this industrial interest, the U.S. Bureau of Reclamation is conducting experimental desalination investigation using geothermal energy.

While no power is yet being produced on a commercial basis in the U.S. portion of the Imperial Valley, San Diego Gas and Electric and Magma Power Co. are testing a binary production system that will transfer heat from hot brines common in this area to low boiling point isobutane, which will in turn drive the turbine.

Brines of the Imperial Valley are far more difficult to handle than The Geysers' dry steam and have thus retarded developments in this area. Installation of the binary production system and successful use of steam flash techniques at Cerro Prieto indicate major utilization of the vast geothermal energy reserves of the Imperial Valley is approaching.

Other California discoveries include Casa Diablo (1959) where 11 wells have been drilled by Magma Energy, Cedarville and Surprise Valley (1959), Calistoga (1960-61), the Honey Lake area at Wendel and Amidee (1962), and Coso Hot Springs (1967). Commercial development has not yet been announced for any of these discoveries.

Outside of California, significant geothermal resources have been discovered in Nevada at Brady's Hot Springs



Well control problems also arise in geothermal drilling. An earlier blowout in The Geysers field remains contained, but not fully controlled.

(1959), Beowawe (1959) and Steamboat Springs (1920); in Oregon at Warner Lakes (1959), Lakeview (1961) and Vale (1973); in New Mexico at Valles Caldera (1960). All these discoveries were in surface seep areas with conspicuous hot spring and fumerolic activities.

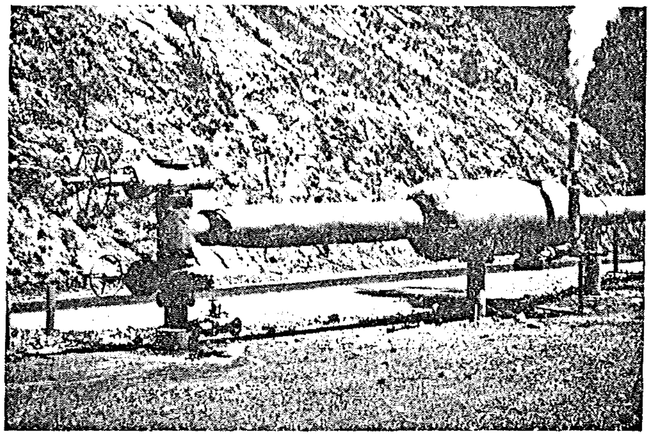
A 1973 discovery near Chandler, Ariz., by Geothermal Kinetics Systems may prove to be a commercial hot water system. This discovery is significant in that no prominent surface thermal phenomena are present and the site is not near one of the federally designated Known Geo-thermal Resource Areas (KGRA).

Geothermal exploration. Most U.S. activity has been concentrated near known hot springs. Primary data source on hot springs is a compilation by the U.S.G.S. supplemented by lists from various state surveys. However, potentially valuable geothermal anomalies not associated with any discernible surface indications may prove to be the industry's best targets by far. Sophisticated exploration technology and regional studies are indicating that geothermal potential exists in areas previously thought to be of no interest.

In normal exploration procedure, target areas resulting from regional crustal studies are evaluated by detailed

TABLE 2—Geothermal power production under development

Country	Field	Planned capacity-1977 megawatts
El Salvador	Ahuachapan	30
Guadeloupe	La Bouillante	30
Japan	Hashimanta-Onuma	10
	Hatchobaru	50
	Katsukonda	50
	Onikobe	25
New Hebrides	?	?
Philippines	Bicol	?
Taiwan	Tatun	10
Turkey	Kizildere	30
United States	Salton Sea	50
	The Geysers	457
Mexico	Cerro Prieto	75
Total		817



Special wellhead equipment for a producing steam well at The Geysers includes insulation and centrifugal separator to remove rock particles that might damage the turbine.

geologic examinations, water geochemistry, and geophysics. Geologic examinations focus on local structure (particularly faulting); degree and kind of rock alteration; type, character, and extent of thermal manifestations; presence, type and age of igneous rocks in the area; and availability of water for recharging the reservoir.

Water geochemistry involves sampling of waters in the area followed by analysis for dissolved mineral content. These chemical data are used as rough indicators of temperature at depth, probable source of water, and probable character of geothermal reservoir fluids.

Passive seismic and electrical resistivity surveys appear to be the best geophysical tools for discovery of geothermal fields. Passive seismic methods involve measurement of microearthquakes and natural ground noise. Microearthquakes are minor and frequent movements along faults, the conduits for geothermal fluids.

In a geothermal area, several hundred microearthquakes per day have been observed. A ground noise survey measures frequency and amplitude of natural ground movements believed to be the result of rheid deformation and phase changes, associated with geothermal fluids. Passive seismic measurements are made with six or more low frequency seismometers telemetered to a central low speed magnetic tape recorder.

Electrical resistivity surveys using dipole-dipole spreads, or roving dipoles with a fixed source dipole, are based on the principle that hot fluids have much lower resistivities than cold fluids. Interpretive difficulty arises in trying to separate effects of highly saline ground waters from the temperature phenomena.

Thermal remote sensing techniques such as infrared would appear to be direct and nearly infallible tools. Unfortunately, background heat from solar radiation is about 20,000 times average earth heat flow. Further, differences in surface color, vegetation, texture and moisture content produce surface temperature variations many times greater than the increased heat flow expected from even shallow subsurface anomalies.

Leasing. Activity on federal lands that comprise some 70% of the western United States remains at a standstill. On July 23, 1973, the Bureau of Land Management issued a second revision to the Proposed Rules and Regulations implementing the Geothermal Leasing Act of 1970, and on Oct. 23, 1973, the final Environmental Impact Statement was issued. The Secretary of Interior has not formally determined that the leasing program will proceed, but expectations are high that he will, possibly late this year.

It should be noted that when the original Proposed Rules and Regulations were published on July 23, 1971, and also when the first revision was published on Nov. 29, 1972, predictions of early leasing were made that were not fulfilled. Given this history of bureaucratic inertia, geothermal explorers have not based their programs on early availability of federal lands.

Most operations have been concentrated in geothermal regions where privately owned lands are available. Also, because of the possibility of classification of adjoining federal lands as "Known Geothermal Resource Areas" and thus subject to competitive lease bidding, few if any operators will disclose exploration results, or even the fact that they are conducting exploration. This latter situation has definitely retarded survey activity.

Nevertheless, geothermal exploration and leasing have attained record levels. Table 3 shows some 30 companies currently engaged in either exploration work and/or land acquisition in the western United States. There are probably other small operators not readily identifiable from available information sources. Compared to two years ago, when almost all exploration was confined to three or four areas in California, the activity level is probably four or five times greater. Some five passive seismic crews and eight resistivity crews are estimated to have been opera-

TABLE 3—1973 U.S. geothermal exploration activity

	California	Oregon	Idaho	Nevada	Utah	New Mexico	Colorado	Arizona
American Oil Shale					x			
Arco	x							
Anadarko Petroleum		x						
Austral Oil							x	
American Thermal Resources	x					x		
Calvert Exploration						x		
Chevron	xo	x						
Courtwright		x						
Dowdle Oil	x	x						
Eason	x	x						
Getty	xo			x				
Geothermal Kinetics Systems	xo		x		x	x		xo
Geothermal Power Corp.	x							
Geothermal Resources Int.	xo							
Gulf Oil	xo	x		xo				
Magma Energy	xo	xo		xo		x		
Pacific Energy	xo	x						
Petroleum Leasing & Development	x							
Petro Lewis (Total Energy Co.)							x	
Phillips	x	x	x	x	x			
Q B Resources International	x							
Raft River REA			x					
San Diego Gas & Electric	xo							
Signal	xo							
Southern Pacific Co.	x							
Sun Oil	x	x	x	x				
Union Oil	xo	x			x	x		
Thermal Power Co. (Colo. & Utah)	xo				x			
Thermex Co.	x	x	x	x	x			
Weyerhauser-PPL		x						

x Land acquisition and/or exploration activity.
o Drilling.

tive during the first half of 1973, establishing all-time highs.

Drilling. Wildcatting has not kept pace with the expanding exploration tempo, due mainly to the ban on federal leasing. Outside of development drilling at The Geysers and in the Imperial Valley, only seven wildcats were drilled in the first six months of 1973—two by Gulf in the Wendell-Amadee, Honey Lake area of northeastern California; one by Magma Energy in Surprise Valley, Calif., and two in the Imperial Valley; one by Pacific Energy in the Clear Lake area, Calif.; and one by Geothermal Kinetics Systems near Chandler, Ariz. Several holes by Gulf and others are planned in California and Oregon in 1973, as soon as permits can be obtained.

In the Imperial Valley, the U.S. Bureau of Reclamation is drilling its second test well in a desalination research program. Chevron, Magma Energy and Union Oil are planning to drill the Heber anomaly in a joint venture with San Diego Gas and Electric. The AEC in the Valles, N.M., area and Battelle Northwest near Marysville, Mont., are planning wells to test the concept of injecting water into "hot rock" to produce geothermal energy.

While interesting from a research point of view, this "hot rock" concept probably will have very little commercial significance for many years to come.

Significance. Geothermal impact on future U.S. energy requirements is theoretically very large, but in a commercial and practical sense, largely unknown. A National Science Foundation study led by Walter J. Hickel, former Secretary of the Interior, predicts that geothermal power could produce 132,000 megawatts of electricity by 1985, or 20% of 1985 U.S. electrical power needs. Power companies and many others are more restrained in their enthusiasm for geothermal power and believe that the contribution of geothermal energy will be 1% or less of the U.S. power supply.

The National Petroleum Council's Committee on U.S. Energy Outlook projects that geothermal energy will meet less than 0.5% of the total forecast U.S. energy consumption in 1975. It is, however, somewhat illogical to argue the future significance of a natural resource without a vigorous and intelligent search having been made.

Thus, until the search is made, extent and value of U.S. geothermal energy resources remain largely unknown, probably lying in the middle ground between pessimistic and optimistic projections.

Growth restraints. Technical, economic and legal problems will prevent any explosive expansion in geothermal activity in the near term. The more significant problems include the following:

►Legal status of geothermal energy is uncertain. Is it gas, water or a mineral? Judicial actions, probably in part at the Supreme Court level, will be needed to establish definitions and determine ownership and tax status.

►Experienced personnel are in short supply. Probably no more than 50 U.S. explorationists and an equivalent number of engineers have any direct experience in development and utilization of geothermal power.

►Much of geothermal technology—exploration, production, power generation—is still in the experimental stage. This is particularly true in the case of hot water systems, which can be expected to comprise most commercial deposits.

►Price of geothermal energy outside areas of high fossil fuel costs such as California may not be competitive with conventional fuels. For example, price of steam from coal in Utah is about 3 mills per kilowatt, or the same as present steam prices at The Geysers.

►Since power rates are set as a percentage of capital as well as operating costs, the lower capital cost of a geothermal power plant may actually deter a utility from developing geothermal energy.

►Reliable techniques still are lacking for determining size, temperature and energy reserves of geothermal reservoirs, data necessary for sound power plant planning.

►The federal government has so far failed to implement the Geothermal Steam Act of 1970, thus preventing exploration in three-quarters of the western United States. A final determination to proceed with leasing and a firm time schedule still are lacking.

Of all of the problems facing this fledgling industry, the last seems the most implausible. Just at the time when a massive assessment of this potentially highly promising energy source is desperately needed, the declared intentions of Congress have become enmeshed in a bureaucratic implementation process.

Nevertheless, even though precluded from exploring the major part of the potential lands, private industry has moved ahead dramatically in the geothermal field, spurred by competitive and economic incentives arising out of the energy crisis. Steady growth in exploration and in the development of new geothermal fields is forecast. ■

About the authors

ROBERT L. FUCHS *graduated from Cornell University with a B.A. in geology in 1951. He received an M.S. in geology from the University of Illinois in 1952. Subsequently, he worked for Mobil Oil Corp. in a variety of exploration assignments, both in the United States and a number of foreign areas. In 1969, he was a co-founder of Intercontinental Energy Corp. and served as senior vice president with that company until 1971, when he became president of Geosystems Corp., a natural resources consulting firm which he heads in New York.*

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