GEOTHERMAL POWER ECONOMICS:

AN ANNOTATED BIBLIOGRAPHY

Hawaii Geothermal Project
University of Hawaii
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N. El-Ramly
R. Peterson
K. K. Seo

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Austin, Carl F., Ward H. Austin, Jr. and G. W. Leonard, "Geothermal Science and Technology: A National Program," Naval Weapons Center, China Lake, California Technical Series 45-029-72, September 1971, 119 pp; in <u>Geothermal Energy Resources and Research</u> (Washington, D. C.: U. S. Government Printing Office, Stock Number 5270-01633, $2.75, June 1972, 465 pp; 341-465).

1.	Abandoned, impeded projects	X	7.	Environmental aspects	X
2.	Areas/Places discussed	X	8.	Exploration aspects	X
3.	By-products; multi-purpose plants	X	9.	Geothermal companies/ pioneers	X
4.	Comparisons with other energy sources; marketing aspects		10.	Hawaii	X
5.	Costs	X	11.	Historical aspects	
6.	Engineering aspects; heat exchange closed systems (freon, butane)		12.	Legal aspects	
			13.	Well data/drilling aspects	X
			14.	Other:	

Authors' abstract:

The major portion of the geothermal prospect called the Coso Thermal Area lies within the instrumented test ranges of the Naval Weapons Center, China Lake, California. In developing plans for scientific utilization of the Coso Thermal Area, the state-of-the-art of geothermal science and technology was reviewed. The review indicated that the development of geothermal deposits for the purpose of generating electricity, providing heat, and obtaining raw materials was a technology in its infancy, with critical aspects subject to uncertainty. This study has resulted in a proposal for a national geothermal science and technology advancement program which will be accomplished by gathering scientific and engineering data from five selected sites representing each of the five principal types of geothermal deposits that are known or hypothesized.

The authors suggest that there are five fundamental geothermal deposit types:

1. Granitic stock heat sources. This type is well-suited for economic development because of the "relative abundance of hydrothermal alteration which provides a seal or cap rock under which high temperatures and pressure can accumulate." This is the deposit type that industry will develop first and includes the following areas: The Geysers, Coso Hot Springs--China Lake, Niland--Imperial Valley, Long Valley--Casa Diablo, and Mono Lake areas in California; Larderello, Italy; Wairakei, New Zealand; Beowawe, Nevada; Cerro Prieto, Mexico; Pauzhetsh and Kunashir areas on the Kamchatka peninsula in Russia; and the Matsukawa, Onikobe, Otake, and Hachimanti areas in Japan.

2. Metamorphic zone heat sources. The only exploration undertaken thus far in this type of system was in the Glenblair-Fort Bragg area of California where industrial drilling took place in the 1960's, but was unsuccessful due to the flow of plastic rock before geothermally significant depths could be reached. Another possible area is the French Broad River hot springs area near Asheville, North Carolina.

3. Wet geothermal gradient heat sources. This type of geothermal area has been undeveloped except for shallow drilling for spas or resorts. Potential areas include the Gulf Coast and hot spring areas in New York, Virginia, and Georgia.

4. Dry geothermal gradient heat sources. No such systems have yet been developed, but potential areas include the northern Atlantic coastal plain and Long Island, New York.

5. Basaltic magma heat sources:

> "In general, the evidence in hand suggests that small basaltic fields that have resulted from deep fracturing (Amboy and Siberian Craters area of California as an example) have not had an adequate heat transfer ability and have not resulted in local hot rock or hot fluid accumulations with any degree of persistence beyond the time of actual vulcanism.
>
> "In the case of extremely recent to ongoing vulcanism associated heat sources, the problems of reservoir mechanics become very severe. For areas such as Island Park in Idaho, the geology appears favorable as the source is large, and it appears well capped and to have had high aqueous extrusions indicating a more than adequate fluid content for the purposes of heat transfer.
>
> "Basaltic systems represent the potential heat source for vast regions of the world. To date, other than for shallow unsuccessful drilling in porous rocks in Hawaii, the concept of basaltic-magma-type geothermals is completely untested. An additional problem in purely basaltic areas is their limited water content and hence the reduced amount of hydrothermal activity and resultant failure to form a seal or cap rock under which high temperatures and high pressure can develop."

Ten thermal springs and wells areas, all of which are considered to be of the basaltic magma heat source type, are located in Hawaii: Maui County--west part of Molokai Island and mouth of Ukumehame Canyon on Maui Island; Hawaii County--on shore at Kawaihae, near shore at Kailua, in and near crater of Mauna Loa volcano, crater of Kilauea volcano, .5 mile northwest of Puu Kukae, near north base of

Puu Kukae hill, on shore 3 miles south of Kapoho, and near Waiwelawela Point. Of 1,006 magma-related springs in the United States (8 in Hawaii), there are an estimated 135 significant magma chambers (5 in Hawaii). Extreme high altitude or satellite photography could be undertaken to determine the limits of the heat source magma chambers.

The authors recommend that the basaltic-magma-type deposit which should be explored is in Hawaii (aerial photo study on Oahu and Hawaii and deep test, probably at Kaneohe Marine Air Station):

> "With the exception of an unsuccessful drilling attempt in Hawaii (low pressure due to porosity of the host rock, and lack of seal in the form of alteration and deposition) basaltic magma systems remain untried. Two types of basaltic systems can be envisioned, a simple purely basaltic magma of a limited size and depth as in the upper portion of the Hawaiian Islands or a large complex basaltic/rhyolitic system such as Island Park, Idaho. Because of the fuel costs of Hawaiian Island power generation, this basaltic environment is recommended as a type deposit, with the actual site to be chosen on the basis of recent vulcanism and exposed structure."

Other topics discussed include (1) exploration criteria, procedures and costs, especially pages 370-372 (prediction of Mono Lake as a geothermally dead area due to absence of seismic epicenters), 380, 385, 423 (some criteria for exploration choices), 424-426, 429-432 (exploration budgets),and 438-458 (listing of thermal springs in the United States); (2) environmental impacts (pages 363, 426-427); (3) byproducts (pages 396,409); and (4) recharge-reinjection phenomena/problems: pages 365, 407, 408-409 (average rainfall as an indication of water recharge, exclusive of ground water migration, for 10 geothermal areas), and 426.

A 38-item bibliography is supplied. One of these items itself has a 570-item bibliography: Austin, Carl F., "Selection Criteria for Geothermal Prospects," Nevada Bureau of Mines Report 13 c, Reno, Nevada, 1966, 93-125.

Axtell, Lawrence H. (California Division of Oil and Gas, Sacramento), "Mono Lake Geothermal Wells Abandoned," California Geology, 25 (March 1972), 66-67.

1. Abandoned, impeded projects	X	7. Environmental aspects	___
2. Areas/Places discussed	X	8. Exploration aspects	___
3. By-products; multi-purpose plants	___	9. Geothermal companies/ pioneers	X
4. Comparisons with other energy sources; marketing aspects	___	10. Hawaii	___
5. Costs	___	11. Historical aspects	___
6. Engineering aspects; heat exchange closed systems (freon, butane)	___	12. Legal aspects	___
		13. Well data/drilling aspects	X
		14. Other: ___	___

Two geothermal test wells have been drilled near Mono Lake. The first (September 1971) was drilled by Geothermal Resources International, Inc. to a depth of 4110 feet. The low temperature and thermal gradient as well as a granite gneiss basement at 3870 feet were factors leading to abandonment.

The second well (November 1971) was drilled by Getty Oil Co. to a depth of 2437 feet, but abandonment was due to the negative factors associated with the first well.

The author concludes that

> "Nevertheless, several factors still qualify this basin as a prime prospecting area:
>
> 1. There is a large subsurface basin filled with water-saturated sediments.
> 2. There is ample evidence of recent volcanism.
> 3. There are boiling hot springs and steam vents on Paoha Island.
> 4. Groundwater temperatures are 30-40° F (15-20° C) above mean ambient temperature.
> 5. There are numerous thermal springs in the basin, as hot as 150° F (65° C)."

Combs, Jim (Institute of Geophysics and Planetary Physics, University of California, Riverside), "Review and Discussion of Geothermal Exploration Techniques," in Compendium of First Day Papers. Presented at the First Conference of the Geothermal Resources Council, El Centro, California, 1972; P. O. Box 1033, Davis, California: Geothermal Resources Council, 1972 ($4), 77 pp.; 49-68.

1. Abandoned, impeded projects		7. Environmental aspects	
2. Areas/Places discussed	X	8. Exploration aspects	X
3. By-products; multi-purpose plants		9. Geothermal companies/ pioneers	
4. Comparisons with other energy sources; marketing aspects		10. Hawaii	
5. Costs		11. Historical aspects	
6. Engineering aspects; heat exchange closed systems (freon, butane)		12. Legal aspects	
		13. Well data/drilling aspects	
		14. Other: ______	

Author's abstract:

Geothermal exploration is a combination of science and technology that attempts to find and delineate economic concentrations of geothermal energy. At present, such concentrations occur where elevated temperatures (150 to 370° C) are found in permeable rocks at depths less than three kilometers. The main objective of any investigation of a geothermal anomaly is to obtain information that can be used to evaluate the four main characteristics of a geothermal reservoir, i.e., to estimate the base temperature, size, permeability and to predict the physical state of the fluid (water or steam). It is concluded that thermal, electrical, geochemical and passive seismic methods of exploration can furnish data about these characteristics and are, therefore, the most useful and important in geothermal exploration. Results obtained on the Mesa geothermal anomaly of the Imperial Valley in Southern California are presented as an illustrative example. Surface geological, geochemical, and geophysical reconnaissance surveys can provide inferences about geothermal reservoirs; however, in the final analysis, the drill will speak the last word.

The author stresses the importance of basic data collection which includes data available in the literature, consideration of possible legal problems (zoning, leasing, taxation), marketing of the resource, and the economics of the program.

A critical variable, with present production techniques, is whether or not the system is vapor dominated or is a hot water system.

The author summarizes the state of the arts in geothermal exploration as follows:

> "Just as petroleum exploration, in its initial stages, took as points of departure the existence of oil seeps, and wells were sited near these seeps in order to pinpoint the deposit in the subsurface; and just as, in many aspects of mining exploration, the existence of gossans, hardpans, etc., was used as the basis for drilling for an economic deposit, so, equally, geothermal exploration has had its beginning in drilling surface manifestations. However, the conclusion was soon reached that the existence of these surface manifestations (geysers, fumaroles, hot springs, mudpots, deposits of sinter, travertine or other hydrothermal activity) in an area indicates the existence of geothermal resources in the subsurface, but does not necessarily indicate the best place for siting wells ... the results obtained by any single [exploration] method are not conclusive and it is to one's advantage to utilize a number of complementary methods."

The Mesa Geothermal Anomaly of the Imperial Valley, California: this is a large potential geothermal reservoir which has no surface thermal manifestations. Geochemical and geological data are incomplete, but geophysical data have been obtained during 1969-1971. Fifty test holes, ranging in depth from 90 to 1394 feet, have been drilled in order to obtain geothermal gradient measurements. Gravity measurements, a seismic noise survey, and an electrical resistivity survey have been undertaken. Conclusions drawn are:

> "Geothermal gradient measurements indicate high temperatures in the shallow subsurface. These thermal conditions are associated with a gravity high (which suggests metamorphism and/or mineralization caused by high temperatures), high seismic ground noise (probably caused by high temperature phenomena), and low resistivity values (caused by high temperatures and/or high salinity)."

As a result of the preliminary explorations, a recommendation has been made to drill a deep geothermal test well.

A 55-item bibliography is supplied.

Koenig, J. B. (California Division of Mines and Geology, San Francisco), "Geothermal Exploration in the Western United States," Geothermics (1970), Special Issue 2, Vol. 2, Part 1, 1-13.

1. Abandoned, impeded projects	X	7. Environmental aspects	X
2. Areas/Places discussed	X	8. Exploration aspects	X
3. By-products; multi-purpose plants	X	9. Geothermal companies/ pioneers	X
4. Comparisons with other energy sources; marketing aspects		10. Hawaii	X
5. Costs		11. Historical aspects	X
6. Engineering aspects; heat exchange closed systems (freon, butane)	X	12. Legal aspects	X
		13. Well data/drilling aspects	X
		14. Other:	

Author's abstract:

Over 90 percent of geothermal phenomena in the United States are in 13 western states, comprising more than 1000 warm and hot spring and fumarole localities. Some 100 can be considered hyperthermal. Exploration in these areas has been in two types: incidental and directed. Incidental exploration has included geologic studies and drilling in thermal areas for purposes other than geothermal development. The Salton Sea, California, geothermal field was explored initally in this manner. Directed exploration has included geological, geophysical and geochemical methods, and has resulted in geothermal test drilling in six states. At least six produceable fields have been discovered: The Geysers, California; Salton Sea, California; Casa Diablo, California; Beowawe, Nevada; Brady's Hot Springs, Nevada; and Yellowstone National Park, Wyoming. Reservoir base temperatures exceed 200° C probably at all of these fields. The Geysers produces dry steam; Salton Sea produces brine; the others produce hot water. Only at The Geysers is electric power being generated: 83,000 kW of capacity has been installed, and facilities for an additional 110,000 kW are being constructed. At Salton Sea there is limited commercial production of calcium chloride from geothermal brine. Many insufficiently explored areas and marginal fields warrant additional directed exploration. These include: Surprise Valley, California; the Carson Sink, Nevada; the high Cascade Range in California, Oregon, and Washington; Valles Caldera, New Mexico; parts of the Aleutian Islands, Alaska; and the island of Hawaii. At

least two geothermal prospects, Clear Lake, California and Steamboat Springs, Nevada, have been abandoned because of problems of waste-water disposal and plugging of wells. These problems are encountered at other fields, including Salton Sea and Casa Diablo. Heat exchanging may provide a means to utilize these marginal fields. Several localities use geothermal water for space heating: outstanding of these is Klamath Falls, Oregon.

The author provides (Table 1) extensive data for over 40 geothermal areas in the United States: (1) number of wells drilled; (2) dates drilled; (3) purpose (geothermal exploration, water for domestic or irrigation use, research into geothermal systems, or oil or gas test); (4) operator (private corporation or public agency); (5) surface phenomena and temperature; (6) drilling data--maximum temperature and depth; (7) miscellaneous, including problems impeding further development.

According to Table 1, 5 wells were drilled in 1961 by Magma Power Company (and associates) at Puna (Kalapana, Pahoa), Hawaii. The surface phenomena were steam seeps and hot ground and temperatures up to 182° F were observed. The deepest well was 692 feet and maximum temperature was 218° F. The steam seeps were associated with the 1959-1960 eruptions of Kilauea and were located in the eastern rift zone.

Detailed analysis is provided for geothermal developments in selected areas: (1) The Geysers; (2) Casa Diablo, where severe legal and fluid disposal problems have thwarted development; (3) Salton Sea ("The contained lithium and cesium of the brine probably exceed known world reserves. For a 20 mw plant, annual production of potassium chloride would exceed 4,000,000 t ... [but] market conditions for sale of large quantities of potash, lithia, table salt, and calcium chloride are not very favorable at present ..."); (4) Brady's Hot Springs, Nevada (the Magma Power Company will "have a 10,000 kW butane heat-exchanging power plant built for test at this site in 1971-72"); (5) Beowawe, Nevada; (6) Yellowstone National Park, Wyoming (includes Mammoth Hot Springs); (7) Steamboat Springs, Nevada; (8) Clear Lake, California; (9) Valles Caldera, New Mexico; (10) Surprise Valley in northeastern California (where there was a mud volcano --geothermal explosion--at Lake City in 1951).

The following are nonelectricity generation utilizations of geothermal phenomena:

1. Several dozen of thermal springs are or have been health resorts and sanitaria, including The Geysers; Calistoga, California; and Steamboat Springs, Nevada.

2. A larger number of thermal spring areas have been used for domestic or agricultural water supplies, including the sole use at Beowawe, Nevada of geothermal fluids for grazing for livestock.

3. Public parks have been created at geothermal locations--Yellowstone National Park, Wyoming (which has 96 thermal areas within it, including Old Faithful Geyser); Katmai National Monument, Alaska; and Lassen Volcanic National Park, California.

4. Space heating via geothermal fluids is taking place at Klamath Falls, Oregon where schools, shops, and homes are serviced by over 350 heat-exchanging system wells; at Boise, Idaho where approximately 200 homes are heated by hot water from two 400 foot wells owned by a private utility company; at Calistoga, California where hotels, homes, and greenhouses are heated by hot geothermal waters; and at a number of other small communities in Nevada, California, Oregon, and Idaho.

5. Production of calcium chloride solution takes place in the Salton Sea geothermal area. Previously a dry-ice plant was located in this general area:

> "In 1927 a group of private investors drilled three holes in an area of fumaroles and mud pots four miles north of the present Salton Sea field, in a search for geothermal steam. Steam was encountered, but in quantities inadequate for power generation. However, carbon dioxide gas was recognized in the discharge, and in 1932 drilling began again. The search for carbon dioxide was successful, and from 1934 to 1954, when rising waters of Salton Sea began to inundate the field, a commercial dry-ice plant was operated at the site ... Ultimately over 65 carbon dioxide wells were drilled, about one half becoming production wells. The productive life span of a carbon dioxide well was about two years; total carbon dioxide production was in excess of 2.5 billion cubic feet."

A 28-item bibliography is supplied.

Muffler, L. J. P. (U. S. Geological Survey, Menlo Park, California), "U. S. Geological Survey Research in Geothermal Resources," in *Compendium of First Day Papers*. Presented at the First Conference of the Geothermal Resources Council, El Centro, California, 1972; P. O. Box 1033, Davis, California: Geothermal Resources Council, 1972 ($4), 77 pp.; 11-18.

1. Abandoned, impeded projects		7. Environmental aspects	
2. Areas/Places discussed	X	8. Exploration aspects	X
3. By-products; multi-purpose plants		9. Geothermal companies/ pioneers	
4. Comparisons with other energy sources; marketing aspects		10. Hawaii	X
5. Costs		11. Historical aspects	
6. Engineering aspects; heat exchange closed systems (freon, butane)		12. Legal aspects	X
		13. Well data/drilling aspects	X
		14. Other:	

Since 1945 The U. S. Geological Survey (U.S.G.S.) has conducted hot spring studies which have led to the conclusion that the hot spring fluids were predominantly of meteoric origin and to the recognition that the SiO_2 content in water is an indicator of high subsurface temperature.

Since 1963 the U.S.G.S. has helped conduct research at the Salton Sea area in California. Results of cooperative research include the demonstration that the hypersaline brine is a potential ore-depositing solution and an estimate of 1.1 billion acre-feet of recoverable water (with salinity less than 35,000 ppm) of which 200 million acre-feet have a temperature exceeding 150° C (302° F).

Since 1966 the U.S.G.S. has been investigating geological aspects of Yellowstone National Park, including the drilling 13 of research holes from 214 to 1088 feet in depth. A theory has been developed to account for the differences between vapor dominated and hot water geothermal systems.

Other areas which have or are being studied are

1. Sulphur Bank area, Clear Lake, California

2. Lake City, northeastern California (site of a major hydrothermal explosion)

3. Long Valley caldera in eastern California (an excellent example of a hot water system)

4. The Geysers in California (the world's largest vapor dominated system)

Other areas discussed are Java (cooperative geothermal exploratory drilling to begin May 1972), Imperial Valley, California (research to determine the base level of seismicity prior to the proposed massive reinjection of fluids), and New Mexico, Gulf Coast, and Hawaii (hydrologic analyses).

The author also discusses U.S.G.S. exploration techniques research and reference is made to land classification and leasing of federal lands under the Geothermal Steam Act of 1970.

A 44-item bibliography is supplied.

Reed, Marshall J. (compiler), "The Economics of Geothermal Exploration." Presented at "Short Course" on Geothermal Energy sponsored by Geothermal Resources Council, Sacramento, California, Spring 1973, 8 pp.

1. Abandoned, impeded projects		7. Environmental aspects	
2. Areas/Places discussed	X	8. Exploration aspects	X
3. By-products; multi-purpose plants		9. Geothermal companies/pioneers	
4. Comparisons with other energy sources; marketing aspects		10. Hawaii	
5. Costs	X	11. Historical aspects	
6. Engineering aspects; heat exchange closed systems (freon, butane)		12. Legal aspects	X
		13. Well data/drilling aspects	X
		14. Other:	

Cost estimates and exploration procedures are developed for a model area in California characterized by hot springs, recent volcanism, and a satisfactory depth of sediments and fractured volcanics to act as a reservoir. A preliminary land check costing $200-300 is the first step:

> "Initially, it must be determined which parts of the prospect area are under private, state, and federal ownership. It is useful to know whether private land consists of large agricultural blocks or of subdivisions. The existence of any parks, monuments, or widlife refugee must be noted for state and federal land. Investigators must determine if patented lands have mineral reservations or if withdrawals of public land have been made."

The author provides a decision point framework within which geothermal exploration proceeds sequentially (dollar figures given in parentheses will denote cost estimates).

Decision point one consists of a literature search ($500), geologic reconnaissance--topography, geologic setting, and human development in the area ($1000), and a comprehensive land check ($1200). Adverse findings would lead to termination of the exploration program.

Decision point two consists of

1. Acquisition of lease holdings. Lease rentals range from \$1 to \$25 per acre per year for 5-10 years. Royalty payments for production range from 8 to 20 percent.

2. Geologic field study (\$4000-\$6000): "Geologic mapping of the prospect should focus on structural features, and detailed information must be obtained on faults and fracture zones. Lithologic study should emphasize the extent of porous and permeable beds, and the age and properties of all volcanic rocks. Information on hydrothermal areas should contain the temperature, flow rate, deposits and extent of all hot springs."

3. Geochemical sampling (\$5000): "Interpretation of the chemical data might show if a steam phase is present at depth and might indicate the temperature of the reservoir. Parameters such as bicarbonate, sulfide, ammonia, conductivity, and pH should be measured in the field..." Analysis should be undertaken for sodium, potassium, silica, boron, chloride, sulfate, calcium, magnesium, iron, and manganese.

4. Geophysical surveys:

(a) Seismic noise study (\$4000-\$7000)--low frequencey ground noise (.5 to 30 Hz) is associated with geothermal fluid movement at depth.

(b) Gravity study (\$1400-\$7000)--in areas of rough terrain, the cost could be considerably higher.

(c) Infrared image study (\$4000).

Decision point three consists of

1. Preparation for deep drilling--road construction and access to drilling site, county land use permits, public hearings and impact statements, regional Water Quality Control Board waste discharge permit, and six months time is needed. No total cost estimate provided.

2. Geothermal gradient and heat flow drilling (\$26,300)--4 heat flow wells and 10 temperature gradient wells to a depth of approximately 500 feet.

3. Electrical resistivity survey (\$3000-\$4000)--the apparent resistivity declines as temperature and salinity of geothermal fluids increase. "In volcanic areas resistivity anomalies are spectacular ..."

4. Microseismic survey (\$5000)--structural information is obtained from microseismic studies of active faults

5. Detailed geochemical survey (\$5000-\$10,000).

Decision point four:

> "The evaluation and leasing of a prospect up to this point could cost $100,000 or more. In estimating the amount to spend on exploration, the cost of evaluating the prospect should be less than one-half the cost of drilling a deep test hole. If there is still insufficient information available after the expenditure of this amount, it is probably more worthwhile to drill a deep test than extend the other exploration techniques."

Average drilling costs for selected locations in California range from $125,000 to $150,000 for 5000 foot depths and $250,000 to $300,000 for 8000 foot depths. Evaluation of the test hole adds 15 to 20 percent to its cost and drilling on steep slopes can create a $40,000 additional expense.

In summary,

> "The evaluation of a prospect, through the drilling of a deep test, will cost $225,000 to $450,000. Many prospects will be dropped from consideration with much less cost. An exploration budget of $1,000,000 might allow the evaluation of as many as ten prospects per year."

Rex, Robert W. (Institite of Geophysics and Planetary Physics, University of California, Riverside), "Cooperative Geological-Geophysical-Geochemical Investigations of Geothermal Resources in the Imperial Valley," in Compendium of the First Day Papers. Presented at the First Conference of the Geothermal Resources Council, El Centro, California, 1972; P. O. Box 1033, Davis, California: Geothermal Resources Council, 1972 ($4), 77 pp.; 45-48.

1. Abandoned, impeded projects		7. Environmental aspects	
2. Areas/Places discussed	X	8. Exploration aspects	X
3. By-products; multi-purpose plants	X	9. Geothermal companies/ pioneers	X
4. Comparisons with other energy sources; marketing aspects		10. Hawaii	
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		14. Other:	

The Imperial Valley (Salton Sea area) has a number of anomalies, including the Mesa, Dunes, Buttes, North Brawley and Heber anomalies. The author focuses primarily on the Mesa anomaly:

"A primary result reported here is that the 'Mesa' geothermal anomaly, previously discovered by R. W. Rex, is large and has a clearly coincident thermal, gravity, and electrical resistivity anomaly."

Geological, geophysical, and geochemical aspects are discussed. The author suggests a considerable potential for this area:

> "The inventory of hot water appears to be sufficiently large that if used for water desalination it might add several million acre-feet of new water to the resources of the lower Colorado River basin. This distilled water would serve to lower river salinity and provide extra water to help meet the U. S.-Mexico treaty commitments. A major fraction of water desalination costs lie in the cost of energy and are related to desalination technology which is directly related to water chemistry. The discovery of low salinity geothermal waters in the Imperial Valley opened the possibility for a major breakthrough in lowered water desalination costs."

Boldizsár, T., "Geothermal Energy Production from Porous Sediments in Hungary," <u>Geothermics</u>, Special Issue 2, Vol. 2, Part 1 (1970), 99-109.

1. Abandoned, impeded projects	___	7. Environmental aspects	___
2. Areas/Places discussed	X	8. Exploration aspects	___
3. By-products; multi-purpose plants	X	9. Geothermal companies/ pioneers	___
4. Comparisons with other energy sources; marketing aspects	___	10. Hawaii	___
5. Costs	___	11. Historical aspects	___
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		13. Well data/drilling aspects	___
		14. Other: ___	___

There are 80 geothermal wells in Hungary and their peak load electrical energy equivalent totals 44 mw. Much of the energy usage is for heating and warm water supplies. An average geothermal well produces 80-90 m^3/hr hot water at about 185-203° F: "Such a well can supply a district with heating for 1200 flats and complementary municipal and public buildings, swimming pools, schools, kindergartens including warm water supply for washing and bathrooms."

In agriculture, the geothermal hot water is used for heating greenhouses, milking rooms, cattle stalls, and chicken houses. In summer the heat is used for drying processes. An average well can supply hot water for a 7000 acre farm and at about 30-40 percent of the cost of coal or oil systems. The number of wells being used in agriculture is increasing at a rate of 8-10 per year.

In 1966 a geothermal borehole in Tápé resulted in the discovery of the biggest oil and gas field in Hungary--this discovery doubled the country's natural gas reserves and increased annual oil production by 7 million barrels.

Grindley, G. W., "The Geology, Structure, and Exploitation of the Wairakei Geothermal Field, Taupo, New Zealand," New Zealand Department of Scientific and Industrial Research, New Zealand Geological Survey Bulletin n.s. 75 (1965), 127 pp.

1. Abandoned, impeded projects	X	7. Environmental aspects	X
2. Areas/Places discussed	X	8. Exploration aspects	X
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6. Engineering aspects; heat exchange closed systems (freon, butane)	X	12. Legal aspects	
		13. Well data/drilling aspects	X
		14. Other:	

Author's abstract:

This bulletin describes the geological aspects of a 15-year investigation of the geothermal resources of the Wairakei hydrothermal field, carried out jointly by the New Zealand Ministry of Works and the D.S.I.R. Since 1950, 120 drillholes (to a maximum depth of 4,550 ft.) have been drilled, and a power station, steam transmission lines, and ancillary structures constructed. Power generation commenced in 1958 and present peak output is 175 MW at 85-90% load factor. Installed capacity is 192 MW, giving a plant factor of 70-90%.

After an historical introduction, Chapters 2-4 deal with the local geology and geological history. The hydrothermal field is underlain by a near-flat, acid volcanic sequence consisting of the following units: Recent pumice cover, Wairakei Breccia, Huka Falls Formation, Haparangi Rhyolite, Waiora Formation, Wairoa Valley Andesite, Wairakei Ignimbrites, Ohakuri Group. The stratified volcanic sequence is draped over a basement horst and thickens eastward and westward into adjoining volcano-tectonic depressions. These major depressions have grown progressively during the Quaternary by differential subsidence along active faults and were not produced catastrophically by cauldron collapse following ignimbrite or rhyolite eruptions, as has been commonly assumed. The bulk of the steam production is obtained from a thick aquifer of pumice, breccias (Waiora aquifer), which is capped by lacustrine shales of the Huka Falls Formation. The Ohakuri Group, drilled in one well, constitutes a lower, pumice breccia aquifer. Hydrothermal water up to 265° C in the Waiora aquifer is fed through linear fissues in the underlying ignimbrites, principally at the crest of a small structural dome. These fissures are believed related to

active, north-east striking, predominantly normal faults, having a small dextral transcurrent component. Major zones of heat liberation have been localised by intersection of secondary north-west cross faults. Fossil, hydrothermal, mud-flow conglomerates intercalated in the mid-Pleistocene Huka Falls Formation, suggest that hydrothermal activity at Wairakei is at least 500,000 years old.

Chapter 5 discusses the siting of drillholes, drilling procedures, performanceof holes, power production and the effects of exploitation. Siting of successful drillholes involves a search for zones of high temperature and permeability. Subsurface fault zones have proved excellent producing zones, and most production holes are sited to intersect them. A cumulative mass discharge, amounting to over 400 million tons of steam and water at the end of 1964, has been accompanied by a substantial pressure drop throughout the hydrothermal aquifer. As water levels have fallen, flash steam has accumulated in the upper parts of the aquifer, where it is drawn on for power production. The natural heat escape of 100,000 kcals/s remains unaltered, largely due to increased steam escape compensating for diminished water flow, and a similar trend is apparent in the shallower drillholes. Temperatures are stable in the deeper parts of the aquifer and in feeding fissures, and cold-water incursion around the margins of the field does not appear to be serious. Mineral deposition, instigated by steam separation, may be the chief factor limiting the performance and life of drill-holes. Availability of water rather than heat appears to be the dominant factor controlling production rates. Increase of power production above present output depends on:

1. More efficient utilisation of natural flash steam.

2. Utilisation of the waste hot water, providing a reliable discharge can be maintained.

3. Utilisation of the largely unknown resource of the lower aquifer, either by accelerated upflow along faults or by deeper drilling.

Chapter 6 considers the location and size of the heat source. Evidence is presented for the location of linear zones of heat liberation marking the subsurface extensions of surface active faults. Evidence for migration of hydrothermal fluids in the lower aquifer from the large rhyolite eruptive centre to the south of Wairakei is discussed, as is the related problem of the source of dry steam tapped in the south of the field. A model of a large, semi-permanent, granite batholith leaking super-critical hydrothermal fluids up fissure zones to heat near-surface aquifers of meteoric water is proposed. Pressure and temperature equilibria of such a magma body may be maintained by gaseous diffusion as suggested by Kennedy (1955).

Chapter 7 compares the Wairakei hydrothermal field with other fields in New Zealand and overseas such as Waiotapu and Kawerau in New Zealand, Larderello and Mt. Amiata in Italy, and fields in California, Iceland, Japan, Kamchatka, and Central America. Many common features of these hydrothermal fields are outlined and discussed with reference to geothermal development.

The author indicates that costs at Wairakei are comparable to other geothermal locations:

> "The present overall cost of power generation at Wairakei is 0.54 d./kWh (= 4.6 mills/kWh). This cost compares favourably with the current costs of power generation at The Geysers in California (4.7 mills/kWh), but is higher than the cost of power generation at Larderello, where power from condensing plants using direct steam is said to cost 3.0 mills/kWh ... The chief difference between costs at Larderello and Wairakei is the relatively cheap cost of steam transmission at Larderello, attributable in part to short pipelines and in part to greater efficiency due to the absence of water and the consequent lack of wellhead separator equipment and expensive drainage."

A possibility that might be examined at Wairakei is that of recharging the aquifer artifically by pumping of the cold or hot water back into the reservoir ... "A problem with artificial recharge is deposition of silica in the recharge wells, and methods of chemical treatment to overcome this are at present being investigated."

Chapter 7 provides a comparison with other geothermal areas: Waiotapu and Kawerau in New Zealand; Larderello, Mont Amiata, and Tolfa in Italy; Iceland; Kamchatka, U.S.S.R.; The Geysers, Casa Diablo, Brady Hot Springs, and Salton Sea, United States; Pathé, Ixtlan, and Mexicali, Mexico; El Salvador; and Japan.

At Waiotapu, progress has been hindered because of calcite deposition which downgrades wells from high pressure to intermediate pressure within a few months. At Kawerau the wells became downgraded after three years of production due to recharge by cooler water.

There is evidence from the Kamchatka experience that "provided the hydrothermal fluids in the fissures are under high thermo-artesian pressure, thick aquifers and capping beds are not essential."

There are approximately 200 known thermal areas in Japan, of which 20 have been prospected for geothermal fluids.

The author provides a table (page 98) which compares these worldwide geothermal areas with respect to (1) geological setting; (2) aquifers; (3) capping beds; (4) faults; and (5) volcanism.

An 85-item bibliography is supplied.

Guiza, Jorge L. (Comision Federal de Electricidad, Mexico), "Flashed Steam Power Plants," in Compendium of First Day Papers. Presented at the First Conference of the Geothermal Resources Council, El Centro, California, 1972; P. O. Box 1033, Davis, California: Geothermal Resources Council, 1972 ($4), 77 pp.; 39-43.

1. Abandoned, impeded projects		7. Environmental aspects	X
2. Areas/Places discussed	X	8. Exploration aspects	
3. By-products; multi-purpose plants	X	9. Geothermal companies/ pioneers	
4. Comparisons with other energy sources; marketing aspects		10. Hawaii	
5. Costs		11. Historical aspects	
6. Engineering aspects; heat exchange closed systems (freon, butane)	X	12. Legal aspects	
		13. Well data/drilling aspects	X
		14. Other:	

This geothermal field is located 16 miles southeast of Mexicali, Mexico and is in the vicinity of Cerro Prieto Volcano, so named for its black color.

A total of 22 wells have been drilled at Cerro Prieto. Three are nonproductive, 17 are producing, and 2 were deep exploratory wells. The average depth has been 4265 feet, and one well was drilled to a depth of 8645 feet after striking basement at 8333 feet. The author describes drilling problems that were encountered.

Descriptions of the steam cycle, power producing equipment, and other engineering data are provided. The steam turbines have been fabricated by the Toshiba Corp. of Japan. Four main leaders conduct the steam to two 37.5 mw turbine generators. The cooling towers are of the induced draft type.

Waste water is flashed in the silencers, discharged, and will be pumped initially into evaporating ponds.

The author believes that the chemicals of the waste water "could be industrially processed, mainly the potassium salts and the sulphur from the gases, to produce pesticides, fertilizers, sulphuric acid, and related by-products. Lithium salts are also a potential product."

Japan National Natural Resources Development Committee, "Present Status and Future Prospect of Geothermal Energy Development in Japan." Paper presented at 6th General Meeting of the Pacific Basin Economic Council, May 1973, 7 pp.

1. Abandoned, impeded projects	X	7. Environmental aspects	
2. Areas/Places discussed	X	8. Exploration aspects	X
3. By-products; multi-purpose plants		9. Geothermal companies/pioneers	X
4. Comparisons with other energy sources; marketing aspects	X	10. Hawaii	
5. Costs	X	11. Historical aspects	X
6. Engineering aspects; heat exchange closed systems (freon, butane)		12. Legal aspects	
		13. Well data/drilling aspects	X
		14. Other:	

Utilization of geothermal waters in Japan dates back to 729 A.D. Dr. Heiji Tachikawa produced geothermal electricity in 1924 and unsuccessfuly drilled a geothermal well in 1927. In the 1940's development occurred at Naruko and Beppu where 10-30 kW of power was generated.

A successful 20 mW geothermal power station opened at Matsukawa in 1966 and a 13 mW plant was completed at Otake in 1967. Construction is underway in three places: (1) Hachimantai-Onuma, with 10 mW; (2) Onikobe, with 25 mW in 1975; and (3) Hatchobaru, with 50 mW in 1975. Exploration is being conducted at the Katsukonda area where 50 mW of electricity appears possible.

Costs appear to be higher:

> "In Japan, the construction of geothermal power plants, as things stand at present, costs more than steam power plants of fossil fuels, and more or less as much as hydro power plants ... the cost for operating a small-scale geothermal plant of 10 to 20 mW roughly corresponds to that for operating a 600-mW heavy-oil-type generator, the largest of the kind used in Japan."

Furthermore, doubt is expressed that small-scale plants will contribute significantly to Japan's energy problem:

"We cannot overlook the rather modest size of the geothermal plants that have been pioneered in Japan. True, in certain cases, this fact may prove advantageous in developing countries, but in the situation prevailing in Japan in which annually we have to keep adding plants capable of yielding some 8,000 mW of power to satisfy the explosively growing demand, it is not a correct solution to have plants equipped with a small number of generators of the conventional type, each with a maximum output of some 50 mW."

Makarenko, F.A., B. F. Mavritsky, B. A. Lokshin, and V. I. Kononov, "Geothermal Resources of the USSR and Prospects for Their Use," Geothermics, Special Issue 2, Vol. 2, Part 2 (1970), 1086-1091.

1. Abandoned, impeded projects		7. Environmental aspects	
2. Areas/Places discussed	X	8. Exploration aspects	
3. By-products; multi-purpose plants	X	9. Geothermal companies/ pioneers	
4. Comparisons with other energy sources; marketing aspects		10. Hawaii	
5. Costs		11. Historical aspects	
6. Engineering aspects; heat exchange closed systems (freon, butane)	X	12. Legal aspects	
		13. Well data/drilling aspects	
		14. Other:	

The authors list 19 locations in the USSR in which there are functioning plants of geothermal heat energy supply: Pauzhetka, Paratunka, Goryachy Plyazh, Chaplinka, Talaya, Kuldur, Iljinka, Ush-Beldyr, Omsk, Tobolsk, Chimkent, Tashkent, Khodzha-Obi-Garm, Mahachkala, Grozny, Cherkessk, Maikop, Zugdidi, and Astara.

Thermal waters are used in the national economy in the following ways:

1. Heating and hot water supply of houses, commercial buildings and plants

2. Heating of agricultural complexes and grounds

3. Commercial enterprises--drying, ferment production, washing of wool

4. Balneological purposes

5. Extraction of valuable chemicals--bromine, iodine, alkaline metals

6. Production of electric energy

For the extraction of chemicals and for the mineral baths, water is required with a temperature not exceeding 104° F.

Thermal waters are also used in the southern regions for refrigeration, using absorption refrigerating machines that require a heat-carrier with temperatures not below 158° F.

Pálmason, G. and J. Zoëga, "Geothermal Energy Developments in Iceland, 1960-1969," Geothermics, Special Issue 2, Vol. 2, Part 1 (1970), 73-76.

1. Abandoned, impeded projects		7. Environmental aspects	
2. Areas/Places discussed	X	8. Exploration aspects	
3. By-products; multi-purpose plants	X	9. Geothermal companies/ pioneers	
4. Comparisons with other energy sources; marketing aspects	X	10. Hawaii	
5. Costs	X	11. Historical aspects	X
6. Engineering aspects; heat exchange closed systems (freon, butane)		12. Legal aspects	
		13. Well data/drilling aspects	X
		14. Other:	

Seven holes have been drilled in the Námafjall area in northern Iceland, primarily for supply steam to a diatomite plant and a small electric power plant of 3 mW capacity.

Seven holes have also been drilled in the Reykjanes areas in southwestern Iceland where exploratory drilling has been undertaken to test the prospects of chemical production from the geothermal brines. Temperature of about 536° F have been recorded in both areas at depths approximately 3000 feet.

Space heating is the primary use for the geothermal fluids. In 1969 almost 90 percent of the population in Reykjavik obtained its heating and hot water supplies from geothermal waters. Although 75 percent comes from Reykjavik, the remainder of the geothermal waters is transported from the Reykir area about 12 miles away. The energy cost of the hot water is 43 percent less than would be the case if imported fuel oil were used. The hot water cost components are drilling, 19%; main pipelines, 11%; storage, 4%; and distribution, 66%.

Feasibility studies are being undertaken for other uses of geothermal energy: heavy water production, sea chemical production, drying of seaweed, and food-processing.

Smith, J. H., "Geothermal Development in New Zealand," Geothermics, Special Issue 2, Vol. 2, Part 1 (1970), 232-247.

1. Abandoned, impeded projects		7. Environmental aspects	X
2. Areas/Places discussed	X	8. Exploration aspects	
3. By-products; multi-purpose plants	X	9. Geothermal companies/ pioneers	
4. Comparisons with other energy sources; marketing aspects		10. Hawaii	
5. Costs		11. Historical aspects	X
6. Engineering aspects; heat exchange closed systems (freon, butane)	X	12. Legal aspects	
		13. Well data/drilling aspects	X
		14. Other:	

Author's Abstract:

Since 1964 exploration wells have been drilled in seven areas. High temperatures up to 306° C were encountered in most of them. The fields at Tauhara and Broadlands are the most productive and development work has been concentrated at the latter. All of the fields are hot water aquifers.

By September 1969 fifteen wells had been drilled at Broadlands to depths ranging between 2500 and 4600 feet, the maximum temperature being 295° C. Many of the wells yield high outputs of steam. Gas in the steam averages 6% to 7% by weight. Drawdown in the aquifer during dischage of a well is considerable and recovery after closure is slow. Some wells are prone to calcite deposition. Development of the field to generate 120 MW is considered reasonable.

Two deep exploratory wells have been drilled; one at Broadlands 7933 feet deep and one at Wairakei 7395 feet deep. These represent an approximate increase of 75% of previously explored depths and have proved the existence of high temperature water at those depths.

For some years geothermal steam has been used at Kawerau for process heat in mills producing newsprint, kraft pulp and sawn timber, and for generating electric power. Five wells currently produce 369,000 lb/hr of steam. Heat exchangers are installed to produce clean steam for some of the processes.

The author provides data for 30 exploration wells--date drilled, cased depth, drilled depth, and wellhead elevation, as well as details of casing programs. The hottest well (583° F) was in Rotokawa where feasibility studies are underway for sulphur mining. An estimated 6 million tons of sulphur are deposited there.

Geothermal exploration at Kawerau began in 1952 with the object of using the steam in a proposed pulp and paper mill and has been successful:

"For some years good use has been made of geothermal steam by the Tasman Pulp and Paper Company who operate the mills which produce newsprint, kraft pulp and sawn timber. At present nearly 400,000 lb/hr of geothermal steam is used for processing and generating a small amount of electric power ..." One of the geothermal wells supplies steam to the timber drying kilns and the wood preparation plant. Additional applications include direct usage of geothermal steam for log handling equipment, recovery boiler shatter sprays, and liquor heaters (the plant's conventional boilers burn black liquor, wood waste, coal or oil). The author suggests that "Undoubtedly geothermal heat can be used more efficiently for heating purposes than for electric power generation and the utilisation at Kawerau is a good example."

A 6-item bibliography is supplied.

Barnea, Joseph (Resouces and Transport Division, United Nations Secretariat), "Multipurpose Exploration and Development of Geothermal Resources," Natural Resources Forum, 1, No. 1 (1971), 55-58.

1. Abandoned, impeded projects		7. Environmental aspects	
2. Areas/Places discussed	X	8. Exploration aspects	
3. By-products; multi-purpose plants	X	9. Geothermal companies/ pioneers	
4. Comparisons with other energy sources; marketing aspects		10. Hawaii	
5. Costs		11. Historical aspects	
6. Engineering aspects; heat exchange closed systems (freon, butane)	X	12. Legal aspects	
		13. Well data/drilling aspects	
		14. Other:	

The author suggests that

> "In geothermal energy, we are at present at the same stage as was the case of river-basin development more than one hundred years ago: all major geothermal fields today are operated for one purpose only. However, we are coming to realize that even more than in river-basin development, possibilities exist for multipurpose application ... We can confidently predict that in the 1970s a change will be seen from single-purpose to multipurpose development."

Three major technological advances should be taken into account in the planning stages of new geothermal projects:

(1) use of heat exchangers employing hot water instead of steam

(2) mineral recovery from geothermal waters--now economically feasible

(3) use of hot water for air conditioning--in the U.S.S.R. and New Zealand lithium bromide absorption machines have been developed which use geothermal waters.

In its El Salvador project, the United Nations is attempting for the first time to determine the technology of re-charge of geothermal fields. In another UN project, the author reports

"In the United Nations geothermal project in Chile, a certain procedure has been provisionally developed for the exploitation of the El Tatio field. First, the hot water-steam mixture from the wells is run through a separator, where the steam is separated for power use while the hot water is directed to a desalination plant to be transformed into fresh water, the salts and minerals being concentrated fourfold. This concentrated brine will then be pumped to a mineral processing plant where the valuable minerals will be extracted. As the hot water reaching the desalination plant will be hot enough for desalination, we shall have a desalination plant operating with no thermal energy input ... concentrating the minerals fourfold through desalination at no cost, the mineral extraction becomes more economically attractive. This is an example of the significance of multipurpose planning ..."

Koenig, James B. (California Division of Mines and Geology), "The Worldwide Status of Geothermal Exporation and Development," in Compendium of First Day Papers. Presented at the First Conference of the Geothermal Resources Council, El Centro, California, 1972; P. O. Box 1033, Davis, California: Geothermal Resources Council, 1972 ($4), 77 pp.; 1-4.

1. Abandoned, impeded projects		7. Environmental aspects	
2. Areas/Places discussed	X	8. Exploration aspects	
3. By-products; multi-purpose plants	X	9. Geothermal companies/ pioneers	
4. Comparisons with other energy sources; marketing aspects	X	10. Hawaii	
5. Costs		11. Historical aspects	
6. Engineering aspects; heat exchange closed systems (freon, butane)	X	12. Legal aspects	
		13. Well data/drilling aspects	
		14. Other:	

Countries currently producing geothermal energy are

1. Italy (390 mw); 2. United States (193 mw);
3. New Zealand (170 mw); 4. Japan (33 mw);
5. Soviet Union (at least 6 mw); 6. Iceland (3 mw).

Planned projects include Mexico (75 mw, Summer 1972) and El Salvador (30 mw).

Exploration is underway in 25 other countries, especially

1. Chile (El Tatio; United Nations)
2. Ethiopia (United Nations)
3. French West Indies (La Bouillante, Guadeloupe)
4. Indonesia (Dieng, Java; Agency for International Development)
5. Kenya (Lake Naivasha; United Nations)
6. Nicaragua (Mamotambo; Agency for International Development)
7. Philippines (Tiwi Hot Springs, Luzon Island)
8. Taiwan (Tatun; corrosion problems, however)
9. Turkey (United Nations; major field discovery, but problem of calcite deposition in wells)

Areas in preliminary stages of exploration include Algeria, Greece, Guatemala, India, Israel, and Yugoslavia.

Countries utilizing lower enthalpy geothermal fluids include

Czechoslovakia and East Germany: space heating and agriculture

Hungary: municipal heat for several cities

Iceland: space heating for 50 percent of the population
heating of green houses
industrial processing, e.g., processing of diatomite

Japan: space heating
industrial processing, e.g., recovery of salt from sea water
hot water resorts

Kenya: use of natural steam to dry pyrethsum leaves for insecticides

Mexico and Kenya: fresh water production from natural steam

New Zealand: space heating
agricultural and industrial processing, e.g., processing of paper pulp

Soviet Union: space heating
agricultural and industrial processing, e.g., defrosting of frozen ground in Siberia

United States: greenhouse operations
heating of buildings
processing of plastic explosives (Steamboat Springs, Nevada).

The author also discusses

1. Development prospects by 1980.
2. Estimates of reserves of geothermal energy.
3. Heat exchange systems.
4. Comparisons with other energy sources.

Muffler, L. J. Patrick and Donald E. White, "Origin of CO_2 in the Salton Sea Geothermal System, Southeastern California, U.S.A.," Proceedings of the 23d International Geological Congress, Prague (1968), 185-194.

1. Abandoned, impeded projects	X	7. Environmental aspects	
2. Areas/Places discussed	X	8. Exploration aspects	
3. By-products; multi-purpose plants	X	9. Geothermal companies/pioneers	
4. Comparisons with other energy sources; marketing aspects		10. Hawaii	
5. Costs		11. Historical aspects	X
6. Engineering aspects; heat exchange closed systems (freon, butane)		12. Legal aspects	
		13. Well data/drilling aspects	X
		14. Other:	

Authors' abstract:

The now-abandoned Imperial Carbon Dioxide Gas Field produced in excess of 18,400,000 cubic meters of CO_2 gas between 1934 and 1954. At least 54 producing wells tapped one or more sandstone reservoirs at depths of 150 to 210 meters and static pressures up to 17 1/2 kg/cm^2. The CO_2 field is part of the Salton Sea geothermal system, from which a concentrated brine rich in Cl, Na, Ca, K, Fe and a host of other elements is currently produced on a pilot basis from depths of 900 to 1,600 meters at temperatures up to 360° C.

The geothermal system is entirely within upper Cenozoic sandstone, siltstone, and claystone of the Colorado River delta. These sedimentary rocks were originally composed of quartz, feldspars, clays, and approximately 8 percent calcite and 4 percent dolomite. Five small rhyolite domes of late Pleistocene or Recent age are present in the area of the geothermal system, and the natural heat flow is about 7 $\mu cal/cm^2/sec$.

Examination of drill-hole cuttings indicates that original carbonates are destroyed and CO_2 liberated in two hydrothermal metamorphic reactions that affect the sediments at depth in the high temperature environment of the geothermal system. At 150° C to 200° C and depths greater than 300 meters, dolomite reacts with kaolinite to produce chlorite, calcite, and CO_2. In the zones of most intense alteration at 300° to 320° C and depths greater than 900 meters, CO_2 is liberated by the breakdown of calcite and the complementary formation of epidote.

We infer that the CO_2 thus liberated from the sediments migrates upward and in part laterally to the shallow CO_2 reservoirs. The quantity of CO_2 liberated in the metamorphism is at least five orders of magnitude greater than the recorded production of CO_2 from the field.

The authors indicate that there have been at least 30 earthquakes of magnitude greater than 5.0 since 1904 in the Salton Sea delta region.

From 1934 to 1943 production records are available for the Imperial Carbon Dioxide Gas Field, which was abandoned in 1945. As of 1943, 66 wells had been drilled, 54 of these encountered carbon dioxide (CO_2), and 43 were commercial producers. The average life of a producing well was 2 years. The carbon dioxide was produced as gas, compressed, and converted into dry ice for marketing.

Between 1957 and 1965 eleven wells were drilled in the Salton Sea geothermal field, ranging in depth from 1673 to 8038 feet. Eight of these wells have produced hot brines which are extremely rich in chlorine (Cl), sodium (Na), calcium (Ca), potassium (K), and iron (Fe). On a pilot basis, electricity has been generated and salts have been extracted.

A 16-item bibliography is supplied.

White, Donald E., "Environments of Generation of Some Base-Metal Ore Deposits," Economic Geology, 63 (June-July 1968), 301-335.

1.	Abandoned, impeded projects		7.	Environmental aspects	
2.	Areas/Places discussed	X	8.	Exploration aspects	
3.	By-products; multi-purpose plants	X	9.	Geothermal companies/ pioneers	
4.	Comparisons with other energy sources; marketing aspects		10.	Hawaii	
5.	Costs		11.	Historical aspects	
6.	Engineering aspects; heat exchange closed systems (freon, butane)		12.	Legal aspects	
			13.	Well data/drilling aspects	X
			14.	Other:	

Five ore-generating systems are examined. Three of these are currently highly productive--Providencia, Mexico; the Mississippi lead-zinc-fluorite-barite deposits; and Nonsuch Shale, Michigan. The other two systems are potential billion-dollar ore bodies and are both geothermal systems--the Salton Sea and the Red Sea geothermals. The Salton Sea geothermal system was discovered in 1961, the Red Sea system in 1964.

Thermal springs in areas of recent volcanism and characterized by high rates of heat flow are typically high in sodium (Na), chlorine (Cl), carbon dioxide, boron, and sulfur. The author asks the following question: "If systems such as Wairakei, New Zealand, Steamboat Springs, Nevada, and Yellowstone Park, Wyoming were drilled deep enough, would reservoirs of Na-Ca [calcium]-Cl brine be found in the lower parts of each plumbing system?"

The Salton Sea geothermal system is potentially an extremely valuable ore-body:

> "The total dissolved [sulfophile] metals in the km^3 of brine at reservoir temperatures and densities are approximately, in short tons: Fe[iron] 10 million, Mn[manganese] 7 million, Zn [zinc] 2 1/2 million, Pb [lead] 450,000, As[arsenic] 60,000, Cu [copper] 30,000, Cd[cadmium], and Ag[silver] 5,000. Non-sulfophile metals of possible economic interest include, in short tons: K[potassium] 85 million, Li[lithium] 1.1 million (the largest known Li resource in the United States),

B[boron] 2.0 million, Rb[rubidium] 500,000, Cs [cesium] 75,000, Th[thallium] 7,000 and Sn[tin] 2,500. If all of the constituents of the brine could be recovered and purified to commercial-grade products, their market value (1968 prices) would exceed 5 billion dollars."

A 175-item bibliography is supplied.

White, Donald E., "Thermal Springs and Epithermal Ore Deposits," Economic Geology, Fiftieth Anniversary Volume, Part 1 (1955), 99-154.

1. Abandoned, impeded projects	X	7. Environmental aspects	
2. Areas/Places discussed	X	8. Exploration aspects	
3. By-products; multi-purpose plants	X	9. Geothermal companies/ pioneers	
4. Comparisons with other energy sources; marketing aspects		10. Hawaii	
5. Costs		11. Historical aspects	X
6. Engineering aspects; heat exchange closed systems (freon, butane)		12. Legal aspects	
		13. Well data/drilling aspects	
		14. Other:	

Portions of Author's Abstract:

The characteristics of five explored hot spring systems are reviewed, focusing attention on features that may be preserved after the activity has ceased. Four systems, including the Upper Basin and Norris Basin of Yellowstone Park, Steamboat Springs, Nevada, and Wairakei, New Zealand have relatively higher temperatures at the surface and at depth. They are volcanic in origin, deriving heat, much mineral matter, and part of their water from a volcanic source ... Sinter at Steamboat and Wairakei contains gold and silver. In many respects, the four high-temperature spring systems are similar to epithermal gold-silver deposits.

The fifth explored system, Sulphur Bank, California, is the only one that has been mined extensively for its metal content, having produced 126,000 flasks of quicksilver.

Nearly all epithermal are deposits that show a relatively close relationship to thermal springs fall into four major groups: Quicksilver (and antimony), manganese (and tungsten), gold-silver, and fluorite. A significant number of quicksilver deposits are associated with thermal springs.... Some manganese deposits are clearly of hot-spring origin, and a few contain notable tungsten ... Silver and gold deposits of the epithermal type appear to be closely related to the high-temperature volcanic hot springs ...

The author provides data for ore recovery from ore deposits that are likely related to hot springs. These include:

1. A small amount of quicksilver has been produced at Ohaeawai hot springs, Ngawha, New Zealand.

2. Between 1935 and 1939 a total of 231 flasks of quicksilver was produced near Coso hot springs, Inyo County, California.

3. In the Mayacmas mountains of California (where The Geysers is located), the Valley mine produced quicksilver until 1890. It now supplies hot water to the Aetna hot-springs resort.

4. At Abraham Hot Springs, Utah, a total of 714 long tons of ore containing 20.8 percent of manganese was produced in 1929-1930.

5. The travertine deposits at Anaconda hot springs, Montana contain 50¢ to $1.50 gold per ton. The hot-spring sinters at Steamboat Springs, Nevada contain as much as 1/3 oz. of gold and 1 1/4 oz. of silver per ton. The Casa Diablo hot-springs in Mono County, California yield 1/2 oz. of silver per ton of sinter. The Comstock district of Nevada, which is 7 miles from Steamboat Springs, has produced close to $400 million in silver and gold.

6. The phosphate and jarosite deposits of Tjiater hot springs of Java have approximately 500,000 tons of jarosite ore which contain 6 percent of potash.

A 149-item bibliography is supplied.

White, Donald E. and C. E. Roberson, "Sulphur Bank, California: A Major Hot-Spring Quicksilver Deposit," in Albert E. J. Engel, Harold L. James, and B. F. Leonard, eds., Petrologic Studies: A Volume to Honor A. F. Buddington, The Geological Society of America, 1962, 397-428.

1. Abandoned, impeded projects		7. Environmental aspects	
2. Areas/Places discussed	X	8. Exploration aspects	
3. By-products; multi-purpose plants	X	9. Geothermal companies/ pioneers	X
4. Comparisons with other energy sources; marketing aspects		10. Hawaii	
5. Costs		11. Historical aspects	X
6. Engineering aspects; heat exchange closed systems (freon, butane)		12. Legal aspects	
		13. Well data/drilling aspects	X
		14. Other:	

Authors' abstract:

Sulphur Bank is the most productive mineral deposit in the world that is clearly related to hot springs. The ore is late Quaternary and is localized in rocks immediately below the water table that existed prior to mining. The hydrothermal alteration and the mineralogy of the veins have been controlled largely by the water table. The upper part of an andesite flow has been above the water table and is extensively altered by sulfuric acid formed by oxidation of H_2S. Characteristic alteration minerals are opal, cristobalite, and anatase where leaching has been intense, and kaolinite, halloysite, alunite, soluble sulfates, and perhaps, jarosite and montmorillonite where acid attack has been less intense.

Native sulfur without cinnabar was abundant near the surface, but, as the water table was approached, sulfur decreased, and cinnabar became abundant. The principal ore bodies were at and below the water table and consisted of cinnabar, marcasite, pyrite, dolomite, calcite, quartz, a zeolite mineral, and all the minerals of the original rocks. Metacinnabar and stibnite were locally common.

The waters deep in the spring system appear to be nearly neutral, but near the water table they become slightly acid because of mixing with downward-percolating waters containing H_2SO_4 resulting from oxidation of H_2S. Films of condensate in the areas of most intense acid leaching may have pH values of 1 or less.

The present thermal waters are very high in total CO_2, boron, ammonia, sodium, and iodine and are low in silica and potassium as compared to many thermal and mineral waters. Chemically and isotopically they are unlike most thermal waters associated with recent volcanism.

The present rate of discharge of water of deep origin is calculated to be about 50 gpm. The average concentration of quicksilver in the ore solutions was probably 0.05-8 ppm, assuming an interval of deposition between 10,000 and 100,000 years and a rate of discharge of water of 50-1000 gpm. The most reasonable estimate is believed to be 0.1-1 ppm.

Present temperatures are relatively low compared to other hot-spring systems of clearly volcanic origin. The present heat flow is on the order of 200,000 cal per sec. or about 12 times "normal" for the area; total heat flow in the past may have been as much as 20 times as much. The heat is almost certainly volcanic in origin, but, despite association with Quaternary volcanic rocks and volcanic heat, the chemical and isotopic compositions of the water and gases now being discharged indicate that these fluids are nonvolcanic in origin.

The authors indicate that Sulphur Bank, Lake County, California has been the fourth largest quicksilver mine in the United States. The other three mines, all in California, are The New Almaden, the New Idria, and the Oat Hill mines. Through 1957, a total of 129,418 flasks of quicksilver had been produced, approximately 65 percent of the original quicksilver reserve.

The deposit, which was discovered in 1856, was first mined for its sulfur. From 1865 to 1868 one thousand tons of sulfur were mined, but a decline in the price of sulfur and a deterioration of the quality of the ore at depth led to the cessation of production. The deposit was first mined for quicksilver in 1873 and production has taken place over the periods 1873-1897, 1899-1902, 1915-1918, 1927-1947, and 1955-1957.

There are five areas where quicksilver is being deposited from water: Sulphur Bank; Amedee Springs, Lassen County, California; Boiling Springs, Valley County, Idaho; Steamboat Springs, Nevada; and Ngawha Springs, North Island, New Zealand.

During 1961, a drillhole was started at Sulphur Bank in an effort to find geothermal steam. This was a joint venture of the Sulphur Bank Geothermal Power Company and Magma Power Company. As of May 1961 a depth of 528 feet had been reached; temperatures were 230° F at 390 feet and 275° F at 528 feet. Hydrothermal minerals included "rather abundant pyrite, some dolomite, and a little zeolite 'S'."

An 62-item bibliography is supplied.

Barton, David B. (Pacific Gas & Electric Company, San Francisco), "The Geysers Power Plant: A Dry Steam Geothermal Facility," in Compendium of First Day Papers. Presented at the First Conference of the Geothermal Resources Council, El Centro, California, 1972; P. O. Box 1033, Davis, California: Geothermal Resources Council, 1972 ($4), 77 pp.; 27-38.

1. Abandoned, impeded projects		7. Environmental aspects	X
2. Areas/Places discussed	X	8. Exploration aspects	
3. By-products; multi-purpose plants	X	9. Geothermal companies/ pioneers	X
4. Comparisons with other energy sources; marketing aspects	X	10. Hawaii	
5. Costs	X	11. Historical aspects	X
6. Engineering aspects; heat exchange closed systems (freon, butane)	X	12. Legal aspects	
		13. Well data/drilling aspects	X
		14. Other:	

The present generating capacity at The Geysers (February 1972) is 192 mw. Companies that have participated in the geothermal steam-winning activities have been Magma Power Company, Thermal Power Company, and Earth Energy Corporation (a subsidiary of Union Oil Company which later was merged into Union as its Geothermal Division). The power plant is owned and operated by Pacific Gas & Electric Company.

A brief history of The Geysers, which is 75 miles north of San Francisco, is provided. The area was discovered in 1847 and subsequently a resort was built there which became a tourist attraction famed for its hot mineral baths.

Current expansion plans call for 100 mw installations. Larger scale for individual plants is not feasible because it is uneconomical to transmit the steam very far.

Wells are 3000 or more feet in depth. The deepest production well is 8500 feet deep; no bottom to the productive zone has been found. The steam reservoir is, according to the steam suppliers and consultants, being depleted.

Engineering aspects of the power plants are described. Because there are no substantial sources of condenser cooling water available, cooling towers are required. Special materials are used in many aspects of the operations due to corrosion problems.

Problems with thermal pollution have been handled by reinjection of the thermal fluids into the steam field through the less productive steam wells. Mention is made of the more serious waste disposal problems of hot water systems (than in dry steam systems) because the quantities of waste water are many times greater.

The total cost of power at The Geysers is "approximately equal to that from our best steam plants. The Geysers power plants are an economical source of electric power for the P. G. & E. system."

Facca, G. and A. Ten Dam, "Geothermal Power Economics," Worldwide Geothermal Exploration Company (10889 Wilshire Blvd., Los Angeles), September 1964, 45 pp.

1. Abandoned, impeded projects	X	7. Environmental aspects	
2. Areas/Places discussed	X	8. Exploration aspects	X
3. By-products; multi-purpose plants		9. Geothermal companies/ pioneers	
4. Comparisons with other energy sources; marketing aspects	X	10. Hawaii	
5. Costs	X	11. Historical aspects	X
6. Engineering aspects; heat exchange closed systems (freon, butane)	X	12. Legal aspects	
		13. Well data/drilling aspects	X
		14. Other:	

The abandoned project refers to a small geothermal turbogenerator which formerly operated in Katanga (Congo).

The authors' Table 8 provides a cost summary for dry steam fields (Larderello, The Geysers) and wet steam fields (Wairakei and Hveragerdi, Iceland):

TABLE 8

COST COMPARISON OPERATING OR PROJECTED GEOTHERMAL POWER PLANTS

	Plant cost $/kW inst	Fixed charges mills/kWh	Steam cost mills/kWh	Operating cost mills/kWh	Generating cost mills kWh
a) non condensing					
1 - Larderello 4-6 MW	66.74	0.92	1.52	0.30	2.74
2 - Larderello 16 MW	60.67	0.83	1.52	0.25	2.60
b) condensing with heat - exchanger					
1 - Larderello No. 2 84 MW	120.00	1.65	1.06	0.25	2.96
c) condensing without heat exchanger					
1 - Larderello No. 3 128 MW	113.00	1.55	0.63	0.20	2.38
2 - Wairakei 192 MW	136.50	1.88	2.27	0.30	4.45
3 - Wairakei 282 MW (projected)	124.96	1.71	2.11	0.30	4.12
4 - The Geysers 28 MW (cost to PGE)	143.00	1.96	0.20	0.20	2.36
5 - Hveragerdi 17 MW (projected)	270.00	3.79	0.98	0.30	5.07

The authors' Table 24 provides a cost comparison between conventional thermal, hydroelectric, and nuclear power plants:

TABLE 24
COST COMPARISON: CONVENTIONAL THERMAL, HYDRO-ELECTRIC AND NUCLEAR POWER PLANTS

	Plant cost $/kW inst	Fixed charges mills kWh	Fuel cost mills/ kWh	Operation cost mills/ kWh	Generating cost mills/ kWh
Conventional thermal plants					
a) average fuel plant	121.00	1.66	5.01	0.56	7.23
(liquid or gas)			to	to	to
			5.30	0.64	7.60
b) modern EEC fuel plant	121.00	1.66	3.20	0.61	5.47
c) average coal plant	150.00	2.06	2.00	0.50	4.56
	to	to	to	to	to
	200.00	2.75	4.00	1.00	7.75
d) modern coal plant (UK)	98.00	1.36	4.68		6.04
Hydroelectric plants					
a) Italy - average 1956		7.26		2.86	10.12
(50 years plantlife)					
b) Italy - average 1958		8.42		2.94	11.36
(50 years plantlife)					
c) Average plant (TYBOUT)	500.00	8.90		1.00	10.90
Nuclear power stations					
a) enriched Uranium and	200.00	2.75	2.00	1.00	5.75
water	to	to	to	to	to
	400.00	5.50	4.00	2.00	11.50
b) natural Uranium and	320.00	4.40	1.00	1.00	6.40
heavy water	to	to	to	to	to
	550.00	7.56	2.00	2.00	11.56
c) Sitewell reactor (UK)	292.00	4.01	1.53	1.17	6.71
d) modern projected reactor	238.00	3.22	1.53	1.17	5.92
e) Magnox type reactor	224.35	3.08	2.34		5.42

It can be noticed from Table 24 that fuel cost is a significant proportion of total generating costs for these nongeothermal plants.

A comparison of the righthandmost columns of Tables 24 and 8 suggests that geothermal power is competitive with rival power plants.

Small scale geothermal plants with transportable turbo-generators are feasible:

"Our summary shows that even small geothermal power plants equipped with 4 mW mobile turbine generators have a generating cost lower than for any conventional, hydroelectric or nuclear plants.

"Such small mobile turbo-generator sets offer the possibility to establish small economical power plants in remote areas where there are possibilities for the development of geothermal energy. With such small units a geothermal field can be economically producing practically from its discovery on ... These geothermal plants allow at least in part a kind of autofinancing during the development stage."

Also provided is a detailed model exploration budget. If adequate exploration is undertaken,the proportion of 1 successful hole against 50 dry holes can be reduced to a ratio of 1 in 20. The model budget is then based on approximately 20 3281 foot deep exploration wells. Despite these conservatively "prudent assumptions," the authors conclude that, for a 140 mW geothermal plant,

"This means that under rather unfavorable exploration conditions, with even a considerable dry hole risk involved, our theoretical geothermal field can generate electricity at a generating cost between 2 and 3 mills per kWh net output. This cost is one of the lowest in the world and would be entirely competitive with the generating cost per kWh net output in the large hydroelectric plants in Scandinavia."

A 28-item bibliography is supplied.

Kaufman, Alvin (Office of Economic Research, New York Public Service Commission), "An Economic Appraisal of Geothermal Energy," Public Utilities Fortnightly (September 30, 1971), 19-23.

1. Abandoned, impeded projects		7. Environmental aspects	X
		8. Exploration aspects	
2. Areas/Places discussed	X	9. Geothermal companies/ pioneers	
3. By-products; multi-purpose plants		10. Hawaii	
4. Comparisons with other energy sources; marketing aspects	X	11. Historical aspects	
		12. Legal aspects	X
5. Costs	X	13. Well data/drilling aspects	
6. Engineering aspects; heat exchange closed systems (freon, butane)	X	14. Other:	

Author's abstract:

A substantial market exists, considerably in excess of presently available supplies, for additional electric energy sources. Considering relative costs, a considerable portion of the necessary load could be generated by geothermal power in this author's view. Despite its low cost, however, the development of geothermal steam deposits to produce electricity poses some problems. Location of the sites may be one. Environmental issues may be another. It is not too early to look for solutions along these lines.

The author indicates that there are geothermal areas in 24 states of the United States, 13 countries in Central and South America, 27 localities in Africa, 23 in Asia, and 20 in the island groups of the Pacific. There is a considerable geothermal energy supply potential in the United States:

> "The United States Geological Survey ... estimates the United States geothermal potential, to a depth of 10 kw [about 6.2 miles], at 6 x 10^{24} calories. This would be equivalent to 9 x 10^{14} tons of coal or 500 times U. S. coal reserves. If recovery is conservatively estimated at one per cent of the potential calories, the United States would have available sufficient geothermal heat to produce 97 x 10^{14} kilowatt-hours. This would be sufficient heat to provide electrical energy for all of the Western United States for many thousands of years."

Cost estimates for The Geysers geothermal plant are provided and a cost per kilowatt-hour comparison is made between coal, geothermal, hydro power, natural gas, nuclear, and oil electric-generating facilities. Geothermal power is competitive with these alternative energy sources, even if the geothermal cost per kilowatt-hour is increased by 50 percent in order to control environmental problems. Abstracted from, however, are transportation costs for electricity which could be substantial for geothermal power.

Geothermal fluid disposal may also add substantially to costs. If the fluids are reinjected into the steam reservoir, reinjection wells at a cost of $20,000 to $250,000 each may be required. The reinjection itself may increase operating costs by approximately 17 percent.

A major obstacle to the development of geothermal power in the United States has been the high incidence of geothermal localities on public lands and the nondevelopment of a legal system for their utilization. Environmental considerations are another obstacle and one aspect of this is the Water Quality Act of 1965:

> "This generally provides, among other things, that the state must maintain the quality of a stream where that quality is higher than the requirements set by the state. New or increased sources of pollution must provide suitable waste treatment to prevent degradation of water quality."

Kaufman, Alvin (Office of Economic Research, New York Public Service Commission), "Geothermal Power: An Economic Evaluation," United States Department of the Interior, Bureau of Mines Information Circular 8230, 1964, 24 pp.

1.	Abandoned, impeded projects	___	7.	Environmental aspects	X
2.	Areas/Places discussed	X	8.	Exploration aspects	___
3.	By-products; multi-purpose plants	X	9.	Geothermal companies/ pioneers	X
4.	Comparisons with other energy sources; marketing aspects	X	10.	Hawaii	X
5.	Costs	X	11.	Historical aspects	X
6.	Engineering aspects; heat exchange closed systems (freon, butane)	X	12.	Legal aspects	___
			13.	Well data/drilling aspects	X
			14.	Other:	___

Author's abstract:

Geothermal plants are competitive with conventional units. A geothermal plant can produce electric energy for 6.70 mills per kwhr, compared with 6.96 mills for coal, 6.74 mills for oil, and 7.04 mills for gas. These costs include fixed and variable charges.

Potential for geothermal power exists in the Western United States, Alaska, and possibly Hawaii. Assuming that the current trend in cost per kilowatt of coal will cease and that the relative cost of gas and oil, already turning upward, may rise considerably more, geothermal energy will be utilized where available, in producing electric energy. It will be used in California first because it is directly competitive with gas- and oil-fired installations there.

A long-term appraisal is difficult because little is known about the sources of geothermal power and the electric generating capacity which the steam fields will support. However, a market for geothermal steam-generated electricity exists within the Western United States.

The author provides extensive cost data:

(1) Geothermal well drilling costs (The Geysers, Iceland, Larderello, and Wairakei).

(2) Cost of producing geothermal power, per kwhr (The Geysers; Iceland; Larderello for noncondensing, indirect heat-

exchange condensing, direct condensing, and conventional plants; Pathe, Mexico; and Wairakei, New Zealand).

(3) Annual cost of electric power at privately financed 600-megawatt plants.

(4) Construction costs and annual production expenses for steam, hydropower, and geothermal plants.

Power plant design is of two basic types--condensing and noncondensing:

"The noncondensing plant is particularly suitable for small units (500 to 6,000 kw) utilizing lower pressures, and is the only unit feasible where the gas content of the steam is high. It has a high rate of steam consumption but a low capital cost. The flowsheet is relatively simple; steam is fed to a turbine, the turbine drives a generator, and then the steam is exhausted to the atmosphere.

"In a condensing plant the flowsheet is essentially the same, except that the steam is eventually condensed to water rather than exhausted ... The power output can be doubled through the use of condensers ...

"Condensing plants require higher capital investments than noncondensing plants. Hence, the condensing plant is not generally economical except for large operations. In dry areas obtaining sufficient condensing water can be a problem, and the use of cooling towers is often required. Consequently, there is an increase in capital investment."

Geothermal energy has been used for space heating in Iceland; Boise, Idaho; Boulder Hot Springs, Gregnon Springs, and Hunters Hot Springs, Montana; and Manley Hot Springs and Circle Hot Springs, Alaska. Another use of geothermal fluids is mineral recovery:

"An additional source of revenue for geothermal plants might be through the recovery of chemicals from the plant effluent. For example, at Larderello, various boron chemicals* are produced as byproducts. A similar material is available at Mammoth Lakes, California, where boron, fluorine, and arsenic are reported in the effluent. The Imperial Valley, California, wells are high in potash, with some lithium, copper, and silver. These latter wells reportedly are capable of flowing at 125,000 pounds of steam and 500,000 pounds of brine per hour. The brines have a 20-percent mineral content. If this material

> is recoverable, it would substantially improve the economics of the project. On the other hand, if the mineral matter is not recoverable, the disposal of such material might prove to be an insuperable problem in the development of the steam wells for electric power generation."

*The author indicates that boric acid, borax, carbon dioxide, boron carbide, and sulfur are manufactured at the Larderello, Italy geothermal installation.

The author discusses current geothermal developments: a California Electric Power Co. contract to build a 15,000 kw generating plant at Casa Diablo Hot Springs; two 30-kw pilot plants at Beppu and Hakone, Japan; a 275-kw plant operating in Katanga; and Hawaii:

> "Hawaii, on the other hand, is deficient in domestic sources of energy. The state is geologically favorable for the discovery of geothermal fluids within close proximity to population centers. However, a recent (1961) exploratory drilling project in the Puna rift, Hawaii Island, was unsuccessful, apparently because of the porous nature of the underlying lava. Therefore, the natural conditions required for production of geothermal power may not exist in Hawaii."

The energy situation in the Western United States and the future of geothermal power are discussed.

A 28-item bibliography is supplied.

Muffler, L. J. P. (U. S. Geological Survey, Menlo Park, California), "Geothermal Resources," *U. S. Geological Survey Professional Paper 820* (1973), 251-261

1. Abandoned, impeded projects		7. Environmental aspects	X
2. Areas/Places discussed	X	8. Exploration aspects	X
3. By-products; multi-purpose plants	X	9. Geothermal companies/ pioneers	
4. Comparisons with other energy sources; marketing aspects		10. Hawaii	
5. Costs		11. Historical aspects	
6. Engineering aspects; heat exchange closed systems (freon, butane)	X	12. Legal aspects	
		13. Well data/drilling aspects	
		14. Other:	

Author's abstract of conclusions:

The geothermal resource base is defined as all the heat above 15° C in the earth's crust, but only a small part of this resource base can properly be considered as a resource. The magnitude of the geothermal resource depends on the evaluation of many physical, technological, economic, environmental, and governmental factors. The physical factors that control the distribution of heat at depth can be evaluated, at least rudely. More tenuous are the assumptions of technology, economics, and governmental policy. These assumptions are critical to geothermal resource estimation, and differences among them are in great part responsible for the vast range in magnitude among different geothermal resource estimates.

Utilization of a greater proportion of the geothermal resource base depends on achieving one or more of the following items:

1. Technological advances that would allow electrical generation from low-temperature reservoirs.

2. Breakthroughs in drilling technology that would permit low-cost drilling of holes to depths greater than 3 km.

3. Development of techniques of artificial stimulation that would increase the productivity of geothermal reservoirs.

4. Expansion of the use of low-grade geothermal resources for such purposes as space heating, product processing, agriculture, and desalination.

The author provides extensive data (Table 49) on nonelectrical utilizations of geothermal resources: (1) space heating (several locations in Iceland and in Hungary; the Caucausus Mountains, Kazakhstan, and Kamchatka areas in Russia; Rotorua, New Zealand; Klamath Falls, Oregon; and Boise, Idaho); (2) air conditioning (Rotorua, New Zealand); (3) agricultural heating--green houses (Iceland, U.S.S.R., Hungary, Japan, Castelnuovo,Italy, and Lakeview, Oregon); (4) product processing (Kawerau, New Zealand--paper; Námafjall, Iceland--diatomite; Shikabe, Hokkaido in Japan--150 tons per year of salt); (5) byproducts (Imperial Valley, California--dry ice, 1934-1943; Larderello, Italy--boron, 1810-1966; Imperial Valley--calcium chloride).

Additionally, "Geothermal energy has potential use in refrigeration and freeze drying ... and some geothermal fluids contain potentially valuable byproducts, such as potassium, lithium, calcium, and other metals..."

Consideration of the alternative uses of geothermal energy is important because "Geothermal reserves (defined as those resources recoverable at present at costs competitive with alternative forms of energy) are clearly limited if one considers only generation of electricity. For the generation of electricity using proved and demonstrated tecnnology, the geothermal reservoir must have a temperature of at least 180° C [356° F]."

The potentials of thermal and chemical pollution as well as the possible need for reinjection are indicated:

> "Geothermal modes of generating electricity share with fossil-fuel and nuclear modes the potential for thermal pollution; indeed, the amount of waste heat per unit of electricity generated is higher for geothermal than for either nuclear or fossil-fuel modes, owing to the low turbine efficiencies at the low geothermal steam pressures. Geothermal effluents, as well as being warm, commonly are mineralized and thus present a chemical pollution hazard to surface or ground waters. Accordingly, most if not all proposed geothermal developments in the United States plan to dispose of unwanted effluent by reinjection into the geothermal reservoir."

The author provides an analysis of prospecting techniques and also discusses specifically four possible breakthroughs in geothermal technology: (1) generation of electricity from low temperature systems via a heat exchanger which boils a secondary fluid such as isobutane or freon (a pilot operation is reported at Paratunka, Kamchatka, U.S.S.R.); (2) development of a nuclear drill that bores holes in rock by progressive melting; (3) geothermal reservoir stimulation by, e.g., nuclear devices; and (4) utilization of geothermal resources as the energy source for desalination.

An 81-item bibliography is supplied.

Aidlin, Joseph W. (General Counsel, Magma Power Company, Los Angeles), "Review of Some of the Legal Problems in Geothermal Development," in Compendium of First Day Papers. Presented at the First Conference of the Geothermal Resources Council, El Centro, California, 1972; P. O. Box 1033, Davis, California: Geothermal Resources Council, 1972 ($4), 77 pp.; 69-77.

1. Abandoned, impeded projects		7. Environmental aspects	X
2. Areas/Places discussed	X	8. Exploration aspects	X
3. By-products; multi-purpose plants		9. Geothermal companies/ pioneers	X
4. Comparisons with other energy sources; marketing aspects		10. Hawaii	
5. Costs		11. Historical aspects	
6. Engineering aspects; heat exchange closed systems (freon, butane)		12. Legal aspects	X
		13. Well data/drilling aspects	
		14. Other:	

The author cites some of the early pioneers of the industry--Magma Power Company, Thermal Power Company, Magma Energy, Union Oil Company, Geothermal Resources International, O'Neill and Ashmun, Morton Salt Company, B. C. McCabe, Harry Falk, Dan McMillan, Carel Otte.

Legal problems are categorized into five areas: (1) ownership of geothermal resources; (2) lease arrangments; (3) tax status; (4) governmental regulations concerning development; (5) environmental aspects.

Those who own lands in which governments have reserved minerals must await a legal determination of whether geothermal resources are considered to be minerals. The author cautions that, despite the Geothermal Steam Act of 1970, "the various reservations of mineral rights in land--federal, state and private--are not worded uniformly. So we can expect considerable conflict and litigation in this area."

Early in 1972 the United States Court of Appeals for the Ninth Circuit sustained a Tax Court ruling that geothermal steam is a depletable mineral gas.

It is the author's belief that

> "The National Environmental Policy Act of 1969, which was intended as a vehicle for increased concern for and attention to our environment, has become the

means of bringing many essential activities of government to a grinding halt ... A recommendation is made that sequential development be authorized in line with the approach adopted by the Board of Supervisors of Imperial County, California:

"It is recognized that a General Plan providing for total development of the resource is needed but that it cannot be a comprehensive General Plan without the input of additional research and data.

"It is therefore the intent of this policy to allow for the complete development of a series of initial projects in addition to exploratory drilling and testing."

The author notes that "the best and only way to find out the extent of the resource is to drill wells."

Anonymous, "The Great Land Rush of '73 ...," Forbes, 111, No. 2 (January 15, 1973), p. 31.

1. Abandoned, impeded projects		7. Environmental aspects	X
2. Areas/Places discussed	X	8. Exploration aspects	X
3. By-products; multi-purpose plants	X	9. Geothermal companies/pioneers	X
4. Comparisons with other energy sources; marketing aspects	X	10. Hawaii	
5. Costs	X	11. Historical aspects	
6. Engineering aspects; heat exchange closed systems (freon, butane)		12. Legal aspects	X
		13. Well data/drilling aspects	
		14. Other:	

Fifty-nine million acres of potential geothermal federal land will be put up for lease in the 14 western states, including Hawaii. The approximately one million acres which have natural steam vents or hot water pools will lease at competitive bidding for about $15 an acre per year and the other lands at $1 an acre per year.

Historically, reasons for the slow growth of geothermal power have been suggested by Dr. Martin Goldsmith of the California Institute of Technology:

> "Because there were power sources available where absolute costs were going down and there were no uncertainties. Coal and oil were cheap and readily available, and when you built a fossil-fueled plant you knew exactly what it would cost, how much power you would get and how long the plant would last. This wasn't so with geothermal power. Now there are uncertainties with conventional plants, and the costs are rising."

In California at The Geysers the cost of electricity from geothermal steam is 5.3 mills per kilowatt hour; for nuclear power the cost is 8.5 to 9 mills and it is 7 mills per kwh for other thermally generated power.

Another reason for the widespread interest in the leasing of these federal lands is the promising nature of some recent explorations. For example, Senturion Sciences, a geothermal research company based in Tulsa, Oklahoma, found six very likely areas out of 31 tests conducted. Production technology is also advancing, and San Diego Gas & Electric and Magma Power (*Forbes*, April 15, 1972) plan to complete a plant in 1973 that will use heat from natural hot water in a heat exchange system.

Bodvarsson, Gunnar (Oregon State University), "Thermal Problems in the Siting of Reinjection Wells," Geothermics (1972), Vol. 1, No. 2, 63-66.

1. Abandoned, impeded projects	___		7. Environmental aspects	X
2. Areas/Places discussed	___		8. Exploration aspects	___
3. By-products; multi-purpose plants	___		9. Geothermal companies/ pioneers	___
4. Comparisons with other energy sources; marketing aspects	___		10. Hawaii	___
5. Costs	___		11. Historical aspects	___
6. Engineering aspects; heat exchange closed systems (freon, butane)	X		12. Legal aspects	___
			13. Well data/drilling aspects	X
			14. Other: ___	___

Author's abstract:

This paper presents a theoretical discussion of the thermal problems involved in the disposal of flash water from geothermal power plants by reinjection. The basic equations for the subsurface temperature field in the reinjection zone are derived both for rocks with intergranular and fracture flow. The extent of the thermal contamination by the reinjected water is discussed. In the case of a continuous mass flow of flash water of 1000 kg/sec for a period of 25 years, the contamination may reach out to as much as 5 kilometers [approximately 3 miles] or more from the point of re-entry, depending on the type of rock involved.

The author summarizes the potential problems of reinjection as follows:

> "First, in order to prevent re-emerging at the surface, the flash water has to be injected into relatively deep formations. In many cases involving low-permeability formations, the pumping pressure and power requirements for reinjection become quite substantial. Second, many types of geothermal flash waters are supersaturated with silica and other minerals. Deposits may occur at the points of re-entry and further aggravate the power problem. Finally, because of the very substantial flows into the ground, there is danger of a thermal contamination of the active producing reservoir. If the reinjection wells

are not properly sited, the flash water, which has a temperature considerably below reservoir conditions, may flow into the production zones and have a detrimental effect on the steam production. This danger is especially acute in the case of geothermal reservoirs producing from a relatively deep ground water table. A small decrease in production temperature may have a considerable influence on the rate of production and on the stability of the producing wells. The siting of reinjection wells is, therefore, of particular importance in these cases."

Bowen, R. G., "Electricity from Geothermal, Nuclear, Coal Sources: An Environmental Impact Comparison," Ore Bin, 33 (November 1971), 197-209.

1. Abandoned, impeded projects		7. Environmental aspects	X
2. Areas/Places discussed	X	8. Exploration aspects	
3. By-products; multi-purpose plants		9. Geothermal companies/ pioneers	
4. Comparisons with other energy sources; marketing aspects	X	10. Hawaii	
5. Costs	~~X~~	11. Historical aspects	
6. Engineering aspects; heat exchange closed systems (freon, butane)	X	12. Legal aspects	X
		13. Well data/drilling aspects	
		14. Other:	

The development of geothermal resources in the United States has been delayed due to (1) availability of low-cost fossil fuels; (2) the remoteness of geothermal areas; (3) the feeling ("illusion") that nuclear plants could supply the additional needs without adverse environmental effects; and (4) the absence until 1970 of a leasing act enabling geothermal development on federal lands (which amount to approximately half the land in the western United States). However, annual demand for electricity has been increasing at double the rate of overall energy demand.

The author focuses on dry steam geothermal areas, such as The Geysers, because "it is the dry steam fields that are the ultimate goal of the exploration effort and it is this type of field that has the potential to make a significant contribution to the power needs of the West." At The Geysers, 2 1/2 quarts of water are injected back into the producing reservoir for each kilowatt of electricity. In hot water fields, however, there are 10 gallons of waste water for each kilowatt: "Returning it to the same reservoir would presumably lower the temperature excessively. Rejecting it at the surface could add heat and deleterious elements to surface water."

It is estimated that by 1980 one-sixth of the freshwater runoff in the United States will be used to cool power plants (one-third by the year 2000): "On the other hand, geothermal plants that utilize dry steam do not require a supplementary source of cooling water ... A geothermal plant, thus, is the only type of thermal power plant that does not compete with other uses of water. Increasing competition for our diminishing supplies of water is probably the single most important reason why our geothermal resources warrant development."

The environmental effects of nuclear reactors, coal-fired generators, and geothermal plants are compared with respect to impacts on (1) land, (2) air, (3) water, and (4) economy. Because of anticipated increasing costs and shortages, power plants fueled by oil and natural gas are not considered. Also not considered are "new and untried" methods of power production--magnetohydrodynamics, fast breeder reactors, and fusion reactors.

The author indicates the economic feasibility of dry steam geothermals:

> "The economic success of power production from a dry steam field has been well proven from the 12-years operating experience at The Geysers field, and from nearly 60 years of experience from the Larderello field in Italy. Because all of the steam-generating equipment is inherent in the earth there is no need to construct it on the site. The furnace, boiler and fuel-handling equipment required in a fossil fuel plant, and the reactor-heat exchanger loop in the nuclear plant, are the most expensive parts of those operations. With the geothermal plant only gathering pipelines are needed to deliver the steam to the turbines. Actual plant construction costs are about two-thirds to three-fourths those of a fossil fuel plant and less than half that of a nuclear plant."

The author also indicates that overly strict zoning regulations could amount to a virtual banning of drilling and development of geothermal resources: "If such regulations are adopted we will have to pay a much higher price for our electricity, both monetarily and environmentally, than if geothermal power is developed to its full potential." If a concerted exploration campaign is undertaken over the next thirty years, a geothermal potential of 100,000 to 1,000,000 mw of electrical capacity could be proved (the present power capacity of the United States is approximately 300,000 mw).

An 11-item bibliography is supplied.

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1. Abandoned, impeded projects		7. Environmental aspects	X
2. Areas/Places discussed	X	8. Exploration aspects	
3. By-products; multi-purpose plants		9. Geothermal companies/ pioneers	
4. Comparisons with other energy sources; marketing aspects	X	10. Hawaii	
5. Costs		11. Historical aspects	
6. Engineering aspects; heat exchange closed systems (freon, butane)	X	12. Legal aspects	
		13. Well data/drilling aspects	
		14. Other:	

Refers to and acknowledges the 51-page critical analysis of the proposed federal geothermal leasing program drawn up for the Sierra Club by the Center for Law and Social Policy in Washington, D. C.

Traditionally, the Westerner is biased against environmental considerations because of his heritage:

> "The ancient Greeks looked upon man as being essentially in himself a spiritual entity whose relationship with his surroundings is transitory, accidental and unimportant in the final reckoning. This concept tended to express itself in two ways. The first was the way of indifference and ascetic withdrawal. The second was man's hedonistic exploitation of his surrroundings for personal enjoyment. The ideas of the Greeks lie at the root of the attitudes toward the environment found in the Western culture which we have inherited. Until the recent past the environment has not been taken seriously. To attempt to sum up a great deal of history in one sentence, men of Western culture have both ignored their environment and despoiled it in good conscience."

Environmental problems associated with geothermal energy include (1) emission of hydrogen sulphide; (2) visual impact from access roads, steam plumes, and transmission lines; (3) noise; (4) odor; (5) creation or intensification of fogs; (6) space requirements and conflicts in land use ("geothermal resources have an unfortunate habit of either being themselves responsible for scenic value--as hot springs or areas of fumarole activity--or of occurring in areas otherwise prized for their scenic character"); (7) land subsidence; and (8) possible triggering of seismic activity.

Sealed geothermal systems utilizing a heat transfer mechanism, however, would have less noise, odor, air and water pollution implications.

The author favorably compares geothermal to other sources of energy:

> "Among the presently considered new energy sources, geothermal power can be readily recognized as one of the more promising in relation both to the environment and to the total human need."

Areas mentioned include The Geysers and Mono Lake, both in California.

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1. Abandoned, impeded projects		7. Environmental aspects	X
2. Areas/Places discussed	X	8. Exploration aspects	X
3. By-products; multi-purpose plants	X	9. Geothermal companies/ pioneers	X
4. Comparisons with other energy sources; marketing aspects	X	10. Hawaii	
5. Costs		11. Historical aspects	X
6. Engineering aspects; heat exchange closed systems (freon, butane)		12. Legal aspects	
		13. Well data/drilling aspects	X
		14. Other:	

The geothermal field in Cerro Prieto, Mexico is located at the southeastern end of the Salton Sea trough and gets its name from a nearly dormant volcano known as "the black hill."

Numerous agencies, companies, and individuals have participated in the Cerro Prieto - Salton Sea geothermal. Southern California Edison Company, which for "the last half dozen years ... has not been able to find a new fossil- or nuclear-fuel power plant site acceptable to opponents of further pollution of the air and water" and Standard Oil of California which "has been unable to solve the problem of sulfur emissions from oil-burning furnaces" have both contributed financially, as have also the National Science Foundation, the United Nations, and the Mexican government.

A prominent stimulus to the exploration efforts has been the nonfulfillment by the United States of its 1944 treaty commitment to deliver 1.5 million acre feet of water to Mexico from the Colorado River. In 1968 the United States Congress authorized the Secretary of the Interior to find 2.5 million acre feet of water per year for delivery to Mexico and three sources are being investigated: (1) a cloud modification program; (2) a sewer-treatment plan; and (3) a geothermal water research program under the direction of Robert Rex of the University of California at Riverside.

Mexico established its Federal Electricity Commission (CEF) in 1939 and one of the CEF organizers was Luis F. de Anda:

> "In those days, the big profit in hotels came from spas where wealthy tourists could soothe their ailing bodies. Therefore, de Anda kept his eyes cocked for warm springs while enjoying his favorite pastime of hiking ... As he clambered over the often volcanic rocks, he came across many bubbling waters in which the Indians cooked potatoes and chickens and boiled off the bark of reeds they then wove into baskets. If the water stayed that hot, de Anda reasoned, Mexico might possess a source of wealth far surpassing the potential of spas."

At Cerro Prieto a power plant with a capacity of 75 mW is scheduled for completion by summer 1972. Evaporative basins have been constructed in which salts will deposit as the escaping water evaporates:

> "These salts and the power together could supply electro chemical plants capable of employing as many as 50,000 primary workers. The usual formulas for servicing such industrial complexes call for five to ten secondary workers in support of each primary job."

Other geothermal areas are also mentioned. Homes and greenhouses have been heated from steam coming from the earth since 1890 in Boise, Idaho and since the 1930's in Klamath Falls, Oregon. During 1970, a new geothermal steam strike was made in Los Alamos, New Mexico and moved "the formerly accepted boundary of the country's [U.S.] geothermal province 800 miles eastward." A research report presented at the 1970 United Nations conference in Pisa, Italy suggested that the geothermal energy potential of the U.S.S.R. exceeds all other Soviet energy sources combined.

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1. Abandoned, impeded projects	X	7. Environmental aspects	X
2. Areas/Places discussed	X	8. Exploration aspects	
3. By-products; multi-purpose plants		9. Geothermal companies/ pioneers	
4. Comparisons with other energy sources; marketing aspects		10. Hawaii	
5. Costs		11. Historical aspects	
6. Engineering aspects; heat exchange closed systems (freon, butane)		12. Legal aspects	X
		13. Well data/drilling aspects	
		14. Other:	

The Department of the Interior is required by the Geothermal Steam Act of 1970 to engage in (1) land classification; (2) leasing regulation; and (3) supervision of operations.

Standards to serve as guidelines for land classification are given in U. S. Geological Survey Circular 647 (Godwin, L. H., and others, "Classification of Public Lands Valuable for Geothermal Steam and Associated Geothermal Resources," 1971).

Approximately 1.8 million acres have been classified as Known Geothermal Resource Areas (KGRA) and 96 million acres (about 58 million acres on federal land) as valuable prospectively for geothermal resources.

Supervisory functions include approval of exploration and development plans as well as inspection of operations.

The author indicates that

> "The leasing sequence for the lands includes: (1) nominations by industry, (2) classification review of the lands for resource potential by U. S. Geological Survey, (3) evaluation of the resource values when applicable for minimum acceptable lease bonus bids, (4) preparation of environmental evaluations and stipulations, (5) rejection of those nominated lands with unacceptable environmental consequences or higher priority land uses, and then (6) either issuance of

noncompetitive leases or holding of competitive lease sales on lands found acceptable for development."

A draft environment statement is being prepared:

> "The regulations and environmental statement are being reviewed to reflect the many comments received--a total of eighty-eight official responses were received--thirty-eight from governmental bodies, twenty-four from corporate interests, and twenty-six from private individuals. Forty-eight of them involved primarily the regulations, while forty responded to the text of the environmental statement. Of the 714 pages received, nearly 70 percent related to the regulations and 30 percent to the environmental statement."

The Department of the Interior, under the National Environmental Protection Agency, is required to list all potential hazards "without regard to their likelihood of occurrence and then to show how our regulations would prevent or mitigate the potential danger." Additionally, the environmental impact of alternative energy sources must be included in environmental statements.

Reference is made to the 1962 well at Niland, California which was, at that time, the largest and hottest geothermal well. The development was and has been complicated, however, by problems with corrosion, scaling, and multiple mineral recovery.

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