Geothermal Energy: An Emerging Major Resource

The earth's heat is a potentially valuable if unconventional source of energy. In the opinion of the university scientists and industrial engineers who have been examining its possibilities, this heat could be used to generate substantial amounts of electricity in the near future; geothermal resources, they believe, are large and can be readily exploited. Three types of resources are being considered—steam, hot water, and hot rock.

At the Geysers in northern California, generating plants that are powered by geothermal steam already produce 180 megawatts of electricity at costs lower than those for comparable plants using fossil or nuclear fuels. Plans have been announced for utilizing sources of hot water, a much more abundant resource than steam, to generate electricity and to ease the chronic water shortage in the southwestern part of the United States. Means of tapping the still larger resources of subterranean hot rock have been proposed but have not yet been proved technically feasible, and field experiments to test the concept have begun.

Despite the optimistic outlook, utilization of geothermal energy is in its infancy and substantial technical problems remain to be solved. Very little exploration for deposits of heat has been done, and prospecting techniques are in the early stages of development. Methods for controlling the corrosiveness of mineral-laden hot water and turbines that can operate efficiently at the low temperatures of many deposits may be crucial to the exploitation of this source of energy on a large scale. Geothermal power plants will not be without potential environmental problems, from air and water pollution to subsidence of land or seismic disturbances caused by pumping, although none of them are regarded as insoluble. Efforts to develop geothermal power have for the most part been confined to industry. Federal support of research has been extremely limited, and indecision in establishing policies to guide the leasing of resources on federal lands has delayed their development.

Geothermal heat has been described as a form of fossil nuclear energy, since it is produced primarily by the decay of radioactive materials within the earth's interior. Radiative and conductive processes transport small amounts of heat to the surface, but large deposits of heat within the earth's crust are apparently the result of geologically recent intrusions of molten rock from the mantle. Where groundwater comes into contact with hot rock, natural deposits of steam or hot water may be formed. Surface manifestations of such deposits, for example, hot springs, are found in many parts of the world, but they appear to be concentrated in regions of recent volcanism and at the boundaries of the major crustal plates (*1*). At sufficient depths, however, hot rock can be found anywhere; in much of the western United States, temperatures of 300°C are estimated to occur within 6000 meters of the surface.

Geothermal Energy Used since 1904

Electric power is being produced commercially from geothermal energy in seven countries, including New Zealand, Japan, and the Soviet Union (*2*). Steam from the region around Larderello, Italy, has been used to generate electricity since 1904. In the United States, the only geothermal resource in commercial use is the Geysers' steam field north of San Francisco. Most of the easily accessible deposits of heat in the United States are believed to lie in the West, although little exploration of hot springs in the eastern part of the country for their energy-producing potential has been done.

At the Geysers, a group of companies headed by the Union Oil Company drill for and produce steam, which is sold to Pacific Gas and Electric (PG & E) and subsequently used by the utility company to generate electricity (Fig. 1). The steam from the wells is collected, filtered to remove abrasive particles, and passed through turbines. The steam is characterized by relatively low pressure and temperature—typically 100 pounds per square inch (1 psi = 6.89×10^3 newtons per square meter) and 205°C at the Geysers compared to 3000 psi and 550°C for the steam in some modern fossil-fueled power plants—and the turbines have a correspondingly different design. The exhaust steam from the turbines is condensed, and the resulting water is used in cooling towers. Most of the water is ultimately evaporated to the atmosphere in these towers, conveying with it the waste heat from the power plant. About 20 percent of the condensed water, containing trace chemicals such as boron and ammonia which would pollute local streams if released, is reinjected into the ground through deep wells.

Because of the lower pressures and temperatures at which they operate, the turbines at the Geysers are about a third less efficient than those of conventional power plants and require about 450 Mw of heat to produce 100 Mw of electricity. Nonetheless the Geysers' plants cost less to build and operate than comparable fossil-fueled or nuclear power plants in California, making geothermal energy the least expensive new source of electricity for PG & E at the present time. The utility plans to add 110 Mw of generating capacity at the Geysers every year for several years. Estimates of the ultimate size of the resources in the Geysers' region range from 1000 to 4000 Mw. How soon the supply of steam from a given well will be depleted is not known, and the uncertainty apparently contributes to the cautiousness with which the utility is expanding its use of geothermal power.

Wells in the Geysers' field, like those in the Larderello region of Italy, produce steam unaccompanied by liquid water, a fortunate circumstance for power generation. Sources of "dry" steam are rare, however; geothermal wells more commonly produce a mixture of steam and hot water, which must be separated before the steam can be used to generate electricity. In some places like New Zealand, the water is simply discarded into stream beds. In others, such as those near the Salton Sea in California, the water has a very high content of dissolved minerals which precludes its discharge into the environment. Most proposals for generating power with steam extracted from hot water wells are based on the assumption that the water would be either reinjected into deep wells or treated to remove its minerals, thus making it available for agricultural or municipal use. Where water is in short supply, the dual purpose use of hot water resources for power and for water has attracted serious consideration. Because water from the wells is already heated, desalting by distillation techniques similar to those being developed for seawater may prove relatively inexpensive.

Alternatively, the hot water could itself be used to generate power by systems in which the heat is first transferred to a secondary fluid, which is then passed through power turbines. Use of secondary power fluids like isobutane which have lower boiling points than water is of particular interest for resources with temperatures less than about 200°C, where ordinary steam turbines become ineffective.

Power turbines designed for isobutane and similar fluids are typically smaller and have fewer stages than steam turbines—a consequence of the higher density of isobutane vapor. Because groundwater would not come in contact with the turbine, corrosion-resistant materials are not needed in their construction. Because isobutane is flammable, however, the secondary fluid system must have very tight seals and other safety features unnecessary with steam. Some heat is lost during its transfer from the hot water to isobutane, but —according to J. H. Anderson of York, Pennsylvania, a consultant to Magma Energy, Inc.—less than is lost by extracting steam from the water. Prototype turbines for use in geothermal power plants have been developed by Magma Energy for San Diego Gas and Electric, which has plans to build a 10 Mw prototype unit near the Salton Sea. Costs for power plants based on secondary fluid technology are uncertain and vary with the temperature of the water supply and the cooling methods used, but in favorable conditions they are estimated by Magma Energy to be competitive with fossil-fueled plants. A geothermal power plant in which secondary fluid turbines are used is now operating in the U.S.S.R.

Proven sources of hot water are located in California, Nevada, New Mexico, Oregon, and Idaho, although none is yet in commercial use, and potential sites have been identified in all of the western states. In Mexico, just south of the U.S. border near Cerro Prieto, a 75-Mw power plant that uses steam separated from hot water is about to begin operation. The Imperial Valley in California has been intensively investigated by Robert Rex, of the University of California at Riverdale, and others, and this region appears most likely to be developed rapidly. Rex has located some eight thermal anomalies in the valley and has estimated the potential resource to be as large as 20,000 Mw of generating capacity and over a billion acre-feet (1 acre-foot = 1.23×10^6 liters) of water (*3*), much of it in the southern portion of the valley where the water is expected to be less brackish than that near the Salton Sea. The Bureau of Reclamation of the Department of Interior has drilled a test well at one of the anomalously hot areas in the region and plans further exploration.

Underground water systems do not come in contact with most of the near-surface deposits of geothermal heat. Hot rock constitutes a third type of resource, but one that is more difficult to exploit than steam or hot water. One proposed method of tapping these "dry" geothermal deposits would be to create artificial cavities by means of conventional or nuclear explosives, and then to circulate water from the surface through the cavity to extract heat from the rock. Uncertainties about the seismic effects from the blast waves and about the economic feasibility of extracting heat from the small cavities that result have so far prevented any attempts to develop the method in any detail.

A second proposed method of getting at dry geothermal deposits, which has attracted considerable attention, originated with a group headed by Morton Smith at the Atomic Energy Commission's Los Alamos Scientific Laboratory (LASL) in New Mexico. In their concept, hydrofracturing techniques similar to those used in petroleum recovery would be employed to create large cracks in a bed of a hard rock such as granite; the cracks would expose a large surface area of the rock to a circulating flow of pressurized water pumped down one well and up another to extract the heat. At the top of the well, the heat would be transferred to a secondary fluid before being delivered to a turbine. Field trials at a site on the edge of an extinct volcano located near Los Alamos are planned to test the concept.

The LASL method, if it can be successfully applied, would make available geothermal resources estimated to be at least ten times the total from steam and hot water. There are uncertainties, however, about how well the hydrofracturing techniques that were developed for cracking sedimentary formations will work in the harder igneous

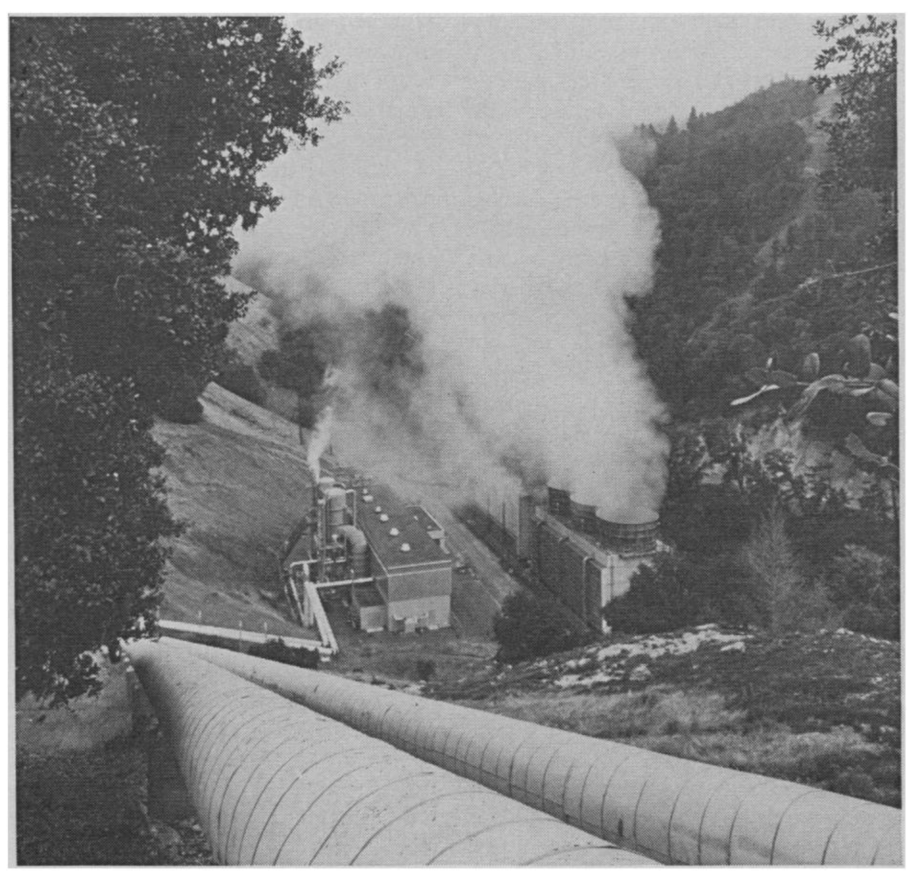

Fig. 1. Two units of the geothermal power plant at the Geysers in northern California. [Pacific Gas and Electric]

rocks. Other assumptions in the LASL concept are that the granite will be impermeable enough to keep pressurized water from leaking away and that, as the granite cools, it will contract in such a way as to extend the initial cracks. The extended cracks would make new hot rock accessible, thus perpetuating the useful life of the system. How granite rocks behave at the temperatures and pressures in question is not very well known; there is no agreement among earth scientists as to the validity of the assumptions. From preliminary calculations, however, the LASL group is confident that their method or some modification of it will work.

Whether dry geothermal resources can be economically competitive with other sources of energy will depend in part on how deep the deposits are, since the expense of drilling through hard rock is expected to be a major cost. But deep drilling may not be necessary to develop sizable resources. The LASL team expects to reach temperatures of about 300°C at depths of 2300 meters at their test site, which is located on the boundary of a magma chamber. David Blackwell of Southern Methodist University recently discovered an area near Helena, Montana, that shows even greater promise as a shallow heat deposit. From measurements of heat flow in mines and wells, he estimates a heat source with a radius of about 4 kilometers and with temperatures between 500° and 700°C, the top of which is 1 to 2 km below the surface. Blackwell found no surface manifestations of the heat source, which he believes to be a recent magma chamber that never erupted to the surface; he points out that much more extensive heat flow measurements will be required to systematically explore for shallow deposits. Improvements in drilling technology could make even deep deposits of heat more economically favorable.

The most likely course of development for geothermal energy, most observers believe, will be the rapid deployment of power plants designed to use steam that is separated from high-temperature water deposits, with subsequent exploitation of low-temperature water reservoirs and dry geothermal deposits. Use of secondary fluids like isobutane rather than steam to drive power turbines is expected to be necessary for low-temperature water and hot rock systems, and may be desirable even at temperatures above 200°C to prevent corrosion and the release of environmentally undesirable substances.

Possible adverse environmental effects of geothermal power plants have received considerable attention at, for example, a United Nations conference in New York earlier this summer; however, there seems to be considerable agreement among both environmentalists and advocates of geothermal power as to the nature of the problems and the methods needed to resolve them. Disposal of waste waters from steam or hot water wells could pose a substantial problem, particularly when the water is highly mineralized. Near the Salton Sea in California the salt content of geothermal waters can be as high as 20 percent, compared to about 3.3 percent in seawater. Even for the less highly mineralized waters found near Cerro Prieto (about 2 percent salt), geothermal plants equivalent to 1000 Mw of generating capacity would produce salt water containing an estimated 12,000 tons of salt per day. Thus disposal of excess water by injection into deep wells or by treatment to produce freshwater is likely to be necessary for most U.S. facilities.

Subsidence May Be a Problem

Reinjection of waste waters could also help to prevent another potential problem, that of land subsidence as the result of removal of large quantities of water from underground reservoirs. Subsidence has occurred in some types of oil fields, and injection of water after extraction of the oil is now standard practice in areas where subsidence could be disastrous. It may be necessary, if geothermal waters are treated in desalting plants and delivered for agricultural or home use, to find other sources of water for reinjection.

Air pollution is also a significant problem, since noxious gases are often a by-product of geothermal wells. Many gases can be easily separated from the steam, but hydrogen sulfide dissolves readily in water and can escape into the atmosphere by evaporation during the cooling process at plants such as the Geysers. Estimates by Martin Goldsmith of the California Institute of Technology (*4*) indicate that the amount of sulfur thus released at the Geysers is equivalent to that emitted by a fossil-fueled plant of the same size burning low-sulfur oil, and that at the hot water plant under construction at Cerro Prieto, the sulfur release might exceed that of comparable fossil-fueled plants burning high-sulfur fuel. Emission controls are being investigated and may eventually be required; restrictions on sulfur release might well provide more incentives to use secondary fluid systems in which emissions are more easily controlled.

Essentially all of the cooling methods being considered for geothermal plants release waste heat into the atmosphere. As a result of the inherent inefficiency of geothermal plants, large amounts of heat and moisture (for wet cooling towers) could be added to the atmosphere in some regions. Although the heat and water from even large-scale geothermal developments would represent at most a few percent of that from natural processes, what effect the additional heat would have on the local weather is not known and would in all probability depend greatly on the prevailing meteorological conditions. The atmosphere is generally considered more capable than lakes and rivers of absorbing and dispersing waste heat without harm to biota.

As with any drilling operation, well blowouts pose a potential problem in the use of geothermal energy. Near faults, injection or withdrawal of water may trigger seismic effects whose nature is not yet well understood, and geophysicists believe that careful monitoring will be necessary. Neither of these problems is considered a serious obstacle to geothermal development.

Geothermal power is not likely to replace either fossil fuels or nuclear fission as major sources of electricity, at least in the near future. But conservative estimates are that 100,000 Mw of generating capacity, a not inconsiderable resource, could with vigorous efforts be developed by the end of this century. The additional prospect of furnishing desalted water for hard-pressed arid regions is also attractive. The remaining problems require concerted effort as well as substantial sums of money in exploration and technology development. For geothermal energy, however, the prospects appear to be worth the price.—ALLEN L. HAMMOND

References

1. L. T. Grose, *Min. Ind. Bull.* **14** (6), 1 (1971); *ibid.* **15** (1), 1 (1972).
2. *Proceedings of the United Nations Symposium on the Development and Utilization of Geothermal Resources, Pisa, Italy* (United Nations, New York, 1970).
3. R. W. Rex, in *California Water*, D. Seckler, Ed. (Univ. of California Press, Berkeley, 1971).
4. M. Goldsmith, "Geothermal resources in California, potentials and problems," *Environmental Quality Laboratory Report No. 5* (California Institute of Technology, Pasadena, 1971).