Geothermal energy is not new. Hot springs and shallow wells have been exploited for space and process heating applications for decades. Electricity has been generated from geothermal steam for over a half century. Until recently such activities have involved unique, isolated anomalies where pure steam or hot water bubbled to the surface (Ref. 1). The large majority of geothermal resources are technically difficult to recover and economically unrewarding. The goal of the Department of Energy's geothermal development and demonstration programs in the next 25 years is to resolve the technical and economic questions and bring geothermal energy fully into the nation's energy supply strategy (Ref. 2).

Of the three primary types of geothermal resources, only hydrothermal (volcanically heated near-surface water) can provide significant energy over the next 25 years (Ref. 1). Hydrothermal resources are currently producing 608 MW(e) at The Geysers in California. The production at The Geysers will reach over 700 MW(e) next year, well over 1000 MW(e) by 1985, and may reach 3000 MW(e) by the end of the century. By that time total hydrothermal production could approach 20,000 MW(e) (Ref. 3). The eventual total U.S. hydrothermal capacity is impossible to estimate but could reach well over 50,000 MW(e) in the mid-twenty-first century (Ref. 2). This is approximately 10% of current U.S. electrical capacity. Space and process heat applications may produce another 50,000 MW(e) equivalent (Ref. 2). Clearly, hydrothermal energy is not a panacea for the nation's energy future but an important component of a diversified energy economy.

There are, however, environmental considerations that could constrain this potential development. The staff of the Oak Ridge National Laboratory's Geothermal Environmental Assessment Team have assessed the environmental impacts of DOE's major programs and more than 15 projects at specific sites. In the course of the environmental assessments the team has identified site characteristics conducive to potentially severe environmental impacts and which tend to recur at site after site. Until now it has been largely unrecognized that these characteristics are closely linked to the nature of the resource and may preclude exploitation of much of it.
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To characterize the common features of hydrothermal sites a summary of the nature of the resources follows: Hydrothermal energy is derived from fluids extracted from volcanically heated aquifers. Fluids can be in two forms, either dry steam (vapor dominated) or hot water (liquid dominated). The only known recoverable dry steam in the United States is at The Geysers; other potential resources are liquid dominated (Ref. 1). Liquid-dominated resources have not yet been commercially developed for electricity production in the United States, although electricity is generated just across the border in Mexico. Liquid resources supply space heat for houses and public buildings in Klamath Falls, Oregon; Boise, Idaho; and several other locations.

Unlike other energy-producing facilities which can be rather freely sited so as to minimize costs and environmental impacts, geothermal facilities must be sited near the resource. Hot fluids or flashed steam cool in pipes even when they are very well insulated. A steam user must be within one mile of the well of origin. This constraint compounds impacts to a resource area because the generation, cooling, and transmission facilities are located in close proximity to the drilling and well field activities.

This siting restriction limits the size of geothermal generating units. Because wells must be separated to avoid interaction [usually about 16 ha (40 acres) apart at depth], it is only possible to surround a generating plant with only about 20 production wells within one mile. A liquid-dominated resource usually generates about 3 MW(e) per well. The more or less standard size generating unit then is 50 to 55 MW(e) (vapor-dominated plants can be larger because of increased net energy per well). The land area affected by such a plant would be about 324 ha (800 acres). Although only about 20% of this would be cleared or excavated for roads, pipelines, well pads, sumps, transmission lines, or generating stations, the entire area is affected visually and the natural setting is disturbed.

Impacts of geothermal facilities fall into two categories: effluent-related (abatable) and site-related (debatable). Effluents from hydrothermal production facilities: atmospheric pollutants, noise, and toxic fluid constituents are extremely variable from resource area to resource area and even between wells within the same field. Of primary concern among gaseous effluents is hydrogen sulfide. Because state effluent and ambient standards are often strict, considerable effort has been allocated to development of effective abatement systems (Ref. 4). In recent months several HgS abatement systems have been demonstrated on operating wells and power plants with good success (Refs. 5,6). Hydrogen sulfide, although possessing an obnoxious odor, is not damaging to vegetation or toxic to wildlife at the concentrations found near geothermal operations (Ref. 7). Other effluents released to the atmosphere as trace metals, boron, and radon have been implicated as potential effluents of concern at some sites (Refs. 1,5). In general, the effect of these effluents is very localized and controllable. Noise from venting and drilling, particularly, is a problem at The Geysers. Drilling using compressed air is the loudest contributor, greater than 100 dBA at 50 ft. This drilling technique, however, is used only in vapor-dominated systems, and is unlikely to be a problem elsewhere. As for venting wells, also greater than 100 dBA, several simple muffler systems have been developed with excellent success. The most important effect of noise attributed...
to geothermal facilities is psychological effects on humans. The sparse population in most geothermal areas (discussed in more detail below) means that drilling and operating facilities will usually be sited some distance from the nearest inhabitant and, therefore, have small impact. Fluids produced in geothermal activities will, almost without exception, be reinjected back into the ground. Thus, impacts from toxic dissolved chemicals will result only from accidents. Dikes, berms, and holding sumps can protect aquatic systems from such contamination. The impacts we consider of greater importance are not effluent-related and abatable but are site characteristics which are mitigatable only through effective planning and site selection.

Hydrothermal resources are associated with recent geologic activity near tectonic plate features (i.e., boundaries, rift zones, and crustal hot spots). This basic feature leads to the four characteristics of concern which typify hydrothermal resource areas. They are located (1) in geologically active regions, (2) in areas with limited water supply, (3) near surface hot springs, and (4) in remote areas of the western United States (the region of most recent geologic activity). Figure 1 is a map of major resource areas where hydrothermal development is likely in the next 25 years.

Association with geologic activity means the likelihood of damaging earthquakes is high. Rift zones like the Imperial Valley have the highest incidence of major earthquakes in the United States (Refs. 8-10). This increases the chance of pipe rupture, settling pond failure and structural damage and, therefore, raises questions of accident impacts and effects on secondary commercial and residential development.

Withdrawal and reinjection of fluids also may stimulate earthquakes (Ref. 1). In certain localities this may affect the rate and type of secondary development. Withdrawals also can result in subsidence of the surface at most hydrothermal sites. In many remote areas this would have little impact, but in sections of the Imperial Valley, where agriculture is dependent on drainage of irrigation waters down a slight slope, the adverse effects of subsidence could be great.

The most common characteristic of geothermal resource areas is limited water supply (Ref. 1). With few exceptions, geothermal development will be in areas where virtually all available water has been allocated. All of the hydrothermal sites we have evaluated, except the Hawaiian site, are at least semi-arid, and 70% of them qualify as deserts, receiving 25 cm (10 in.) or less precipitation per year. Most near-term geothermal electric plants will utilize a flash-stream process. The condensate of the flashed geothermal fluid provides the cooling water. However, high salinity or low temperatures of the geothermal fluid may preclude the flash-stream system in some localities, and make-up cooling water would be required. Furthermore, in some areas the requirement will be made that a fluid volume equal to that extracted from the ground will have to be injected back into the ground to mitigate land subsidence. Water will have to be procured for these uses and for the secondary development and process uses. In only a few areas is water available to provide these needs. There are also questions concerning the effect on near-surface aquifers of depleting the deep, hydrothermal reservoirs. In addition, the potential exists for a drilling or reinjection
LIKELY AREAS FOR HYDROTHERMAL DEVELOPMENT

Hawaii

Geyser

Mono-Lake Valley

Reno Hot Springs

Imperial Valley

Cerro Prieto

300°

155°

22°

20°

Hawaii
accident to cause the contamination of a near-surface aquifer, and, thereby, degrade a limited resource.

One of the most striking features common to hydrothermal areas is their remoteness. The counties in which projects are located have an average population density of only 1.3 persons per square kilometer (versus 30 persons/km² for the coterminous United States). Resource areas are 80 to 240 km (50-150 miles) from the load center where the electricity will be used. It is doubtful that any utility will invest the money to construct such long transmission lines to transport the electricity generated, to import workers, or to make other capital investments for a single 55-MW(e) plant. It can be reasonably assumed that a resource area will not be developed unless it is shown that at least eight generating units [400 MW(e)] can be supported. With roughly 324 ha (800 acres) per generating unit affected, this means a typical hydrothermal resource area will have at least 2600 ha (26 km² or 10 sq miles) of disturbance. Such a large development in remote areas of the west leads to potential interference with scenic and wilderness priorities and with important wildlife habitat.

Remoteness and rugged topography resulting from recent tectonic activity are not only associated with geothermal resources but are often basic components of aesthetically dramatic landscapes. These elements have produced several important natural landmarks which are protected from federally sponsored disturbance. Some potential geothermal resources are already set aside as National Monuments and National Parks because of their high scenic quality (e.g., Craters of the Moon, Lassen, and Yellowstone). Because of their roadless status, several potential geothermal resource areas are also potential wilderness preserves. Thus, geothermal development will often conflict with important aesthetic values.

Geothermal development of remote areas also often conflicts with preservation of important biological values. Many species which were once widely distributed are now relegated to remote areas, because of persecution (cougar and golden eagle), pesticides (peregrine falcon), or habitat requirements (elk and bighorned sheep). These and other rare, endangered, or otherwise valued species are often associated with geothermal projects (Refs. 11-13). Projects near The Geysers, the Salton Sea, in southern Idaho, and in Northern New Mexico have encountered issues regarding disturbance of important wildlife habitat serious enough to require restriction or modification of the project, establishment of buffer zones, or outright cancellation. Endangered plants, unique or unusual biotic assemblages, and uniquely adapted populations (Long Valley's fall spawning rainbow trout) are often associated with thermal waters or geothermally altered soils.

Hydrothermal resources are usually identified by surface manifestations (i.e., hot springs, fumaroles or cinder cones). Mineral hot springs attracted settlers and pioneers and were often gathering places in the arid west. The result is that many now have historic importance and as such have been or could be declared National Historic Sites which restricts the uses that can be made of an area (Refs. 14,15).

Native American cultures also were attracted by the hot springs and fumaroles which characterize hydrothermal resources. They used the hot springs and sulfur
deposits for medicines and remedies; but, more important, many aboriginal cultures attached religious significance to volcanoes and hot springs (Refs. 5, 14). These beliefs are still very important to many of the remaining members of such cultures. In the cases of Hawaii, Coso Hot Springs, Valles Caldera, and Long Valley, important cultural and religious resources are closely associated with the geothermal area. Conflicts with cultural values are possible in many, if not most, of the geothermal areas. Salvage archaeology has been increasingly attacked as an inappropriate method for the resolution of these conflicts. Preference is given to complete avoidance of historic and archaeologic sites. In light of the extensive protection afforded by the Historic Preservation Act of 1966, the Antiquities Act, and executive orders, development of many geothermal areas may be precluded or restricted (Refs. 15, 16).

The unavoidable characteristics of geothermal field development are drilling activity, water evaporation, a conspicuous plant with cooling towers, many dirt roads, pipelines, and transmission lines running over the landscape. These characteristics interfere directly with cultural, aesthetic, and wildlife resources that may be present. Up to now, the only industry criteria for site selection and processes used have been resource characteristics, such as temperature and salinity of the fluids and land availability. It must be recognized that conflicts will arise because of seismic activity, lack of water, cultural-religious significance, and remoteness of hydrothermal resource areas. The intelligence that is brought to bear on site selection and environmental planning will decide in large part the success of geothermal energy commercialization.


REFERENCES


