CHAPTER 3

GEOTHERMAL ENERGY

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Geothermal energy, utilizing the natural heat of the Earth, is a current and potential source of power in some locations. The real promise of geothermal energy lies in its utilization for electric power generation. Currently this takes place in only a few locales, the Geysers in Lake and Sonoma Counties being the only operating geothermal power plants in the United States. Although geothermally produced power figures only slightly in the total energy picture, it contributes approximately 15% at present to Bay Area electricity production, with a potential for expansion. Further development hinges on economics, environmental and social impacts, location, technology, and greater knowledge about the resource in general.

There are three major forms in which geothermal resources occur: hydrothermal, geopressured, and dry, hot rock. Each of these types has unique characteristics, potentials, and problems which affect its utilization. Hydrothermal reservoirs are the most desirable, given present technology. These can be of two types, "dry-steam" or "wet-steam: depending on whether steam or hot water circulates in the system. The dry steam, or vapor dominated system, lends itself most readily to electric generation because the steam can be fed directly into turbines. Dry-steam fields are rare, however, The Geysers being the only proven field in the U.S.[8]

Much more common are the wet-steam hydrothermal reservoirs. To utilize these, hot water flows or is pumped to the surface and either changes to steam with a sudden pressure drop or is sent through a heat exchanger to gasify a working fluid such as butane. The turbine then is operated either by steam or gas.[8] The water dominated hydrothermal resources are more difficult to work with both technologically and environmentally.

The second type of reservoir is geopressured, or hot water trapped under pressure. Little is known about this type, but as an energy source its potential is three-fold: a) the water, under pressure, can drive a turbine much like water flowing over a dam; b) the associated heat can be used to evaporate a gas which will in turn run a turbine; c) the considerable methane gas trapped with the water can be used alone as fuel.[16]

Dry hot rock, the third reservoir type, is potentially the most widely distributed. It consists of hot rocks a few hundred feet below the Earth's surface. Utilization of this source requires fracturing of the rock, pumping water into the artificial reservoir, and then extracting the steam. At this time both hot rock and geopressured systems are in the planning stages and no commercial development is expected before 1995.[8]

In the Bay Area only the dry-steam system at The Geysers appears on the federal list of Known Geothermal Resources Areas (KGRA). No hot rock resources have been located here and the likelihood of any being discovered is very slim. Geopressured reservoirs currently are known to exist only along the Gulf of Mexico.

THE GEYSERS

The Geysers power plant is located in the rugged Mayacmas Mountains of northeastern Sonoma County, about eighty miles north of San Francisco. The plant is operated by PG&E. It is the only geothermal plant in the United States, and it is the largest such plant in the world. The steam vents and hot springs were discover-

ed in 1847. Due to the successful generation of electric power at Larderello, Italy, from natural steam, plans were made to drill for additional steam at The Geysers. Between 1921 and 1925, eight wells were drilled, but the project failed for lack of local demand for electric power. Interest was renewed in geothermal power generation in the 1950's when Magma and Thermal Power Companies obtained a ninety-nine year lease and drilled six wells. PG&E became involved in 1958 when it signed a contract to purchase steam. Geothermal electric power generation became a reality in 1960 when PG&E began producing 12,500kW from a plant supplied with 250,000lbs of steam per hour by four wells. Since then, drilling has taken place to ever increasing depths, and the total generating capacity has gradually increased to the present total of 522,000kW gross, which is generated by eleven electricity generating units, each supplied by a number of wells. [12] Due to operating requirements of The Geysers facilities, the net production is 502,000kW, which is approximately 11% of the present Bay Area consumption.

There are 8,112 proven acres of steam, and 13,000 probably productive acres for geothermal electric power generation at The Geysers. There are two distinct steam reservoirs in The Geysers region: a shallow one up to 15,000 feet deep, and a deeper one below 15,000 feet. The deeper reservoir has great promise in that its known area is more than ten square miles, and these deeper wells have shown no significant changes in productive capacity over the past few years.[2]

The overall efficiency of The Geysers electrical generation facilities is only 15%. The units use dry, slightly-heated geothermal steam at a relatively low pressure of 100psi and a relatively low temperature of 355^{o}F, with an average steam production of 150,000 pounds per hour per well. The suppliers tap the reservoir of steam by drilling wells ranging from about 2,000 to 10,000 feet deep, but many earlier wells were much shallower. As of 1977, there are 124 productive wells, with an average depth of 6,000 feet; the deepest well is 10,300 feet deep. The average drilling time is forty-five days, and it cost approximately $750,000 to drill an average well in 1977.[3]

New generating sites are generally being developed for a production capability of 110,000kW. These sites require about two to three acres of land and are usually located in the center of twelve to fourteen operating wells, as compared to an average of sixteen wells for the older sites. The size of the units is limited by the difficulty of transporting large equipment into The Geysers area and by the length of pipes carrying steam from the wells. In addition, the steam turbines are much larger than those used in thermal power plants of equivalent capacity, due to design requirements for the relatively low pressure and temperature of the steam.[13]

Because heat dissipates rapidly, geothermal fluids cannot be transported far from their point of recovery without suffering a decline in heat and pressure values. For this reason, the heat energy must be converted to electric energy within a few hundred yards of the source, then it is distributed to the consumers via the power transmission grid.[13]

Generation of electricity is not the only effective means of using geothermal energy. Space heating, agriculture, and the heating of swimming pools are all possible means of geothermal utilization. However since geothermal fluids can not be transported without serious loss of efficiency and since The Geysers are located at some distance from a large population center and in rugged terrain, it would not be feasible to make alternative use of the steam except on a very small localized basis.[10]

The Stanford Research Institute has shown that goethermal energy from The Geysers is estimated to be the lowest cost alternative for base load power generation for PG&E compared to nuclear, conventional oil, combined cycle oil, and coal (Table 1). The 1976 cost is only 20.4 mills per kWh, even with a 90% H_2S emission control system built into the power plant. This is about two-thirds the cost of a combined cycle oil plant, and is appreciably lower than the other base load alternatives.[7] Only hydropower has been found to be cheaper, but only in certain situations, for base load generation of electricity.[12] Geothermal units must be operated as base load units, running at peak capacity day and night, because of the long, complicated start up and shut down procedures necessary to prevent dislodging of sand and grit in the wells, which could be damaging to the generating turbines.[9]

ENVIRONMENTAL IMPACT

Geothermal energy developments are unique in their effect on the environment. Unlike nuclear or fossil fuels, the total fuel cycle takes place in one location, the site of power production facilities.[4] Much of the impact occurs during development stages. The impacts of full scale operations are less than those encountered in the initial phases.[15]

A major factor in considering geothermal development is the huge land requirement. A 100MW power plant at The Geysers requires up to 12 square miles of land to insure proper well spacing.[4] Of this land, only 7%-10% of the surface actually is developed.[20]

In developing the facilities, roads, well sites, and power plants were constructed. These entailed surface disturbances. The situation is magnified by the mountainous terrain of The Geysers area, requiring moderate amounts of cut and fill work. The rearrangements of the landscape cause increased erosion and

TYPE	ESTIMATED COSTS							
	1976				1985			
	FIXED CHARGES	OPERATION & MAINT.	FUEL	TOTAL	FIXED CHARGES	OPERATION & MAINT.	FUEL	TOTAL
NUCLEAR	24.4	1.1	3.5	29.0	24.4	1.1	4.0	29.5
CONVENTIONAL OIL	9.6	0.9	23.0	33.5	9.6	0.9	28.0	38.5
COMBINED CYCLE OIL	8.4	2.0	21.8	32.2	8.4	2.0	26.5	36.9
COAL	15.3	2.2	11.8	29.3	15.3	2.2	13.9	31.4
GEOTHERMAL (With 90% H_2S Emission Control)	6.8	0.6	13.0	20.4	6.8	0.6	15.0	22.4

NOTE: Fixed Charges include the Cost of Money (composite of debt and equity), depreciation/amortization, interim replacement, insurance, and taxes.

Source: California Energy Resources and Development Commission, 1977, The Geothermal Alternative To The Proposed PG&E Combined Cycle Plant, Docket No. 76-NOI-3.

TABLE 1

Busbar Costs* For Alternative Methods of Baseload Electric Power Generation (Costs in mills/kWh - constant 1976 dollars).

* Total cost of power generation to point of delivery to customer.

contribute to visual degradation of the site.

Development of The Geysers generating facilities has disrupted vegetation. The predominantly woodland-brushland biome is not affected directly by the steam except over a long period in a small concentrated area. Temporary or permanent damage to vegetation does occur as a result of the construction of roads, well sites, pipelines and power plants. After cutting and grading, a minimum of two to three years are required for the vegetation to recover, much longer on steep, rocky cuts suffering erosion.[20]

Replanting with natural vegetation is being carried out in some places at The Geysers. The process is not an easy one on steep cut sides, however, and the success is not as great.[6] The chaparral vegetation is replaced purposely by grassland on each side of the pipelines to reduce fire hazard.[20]

Disruption of vegetation has important effects on the habitat of wildlife and fish. The Geysers are a native habitat for deer, small game, numerous birds (including golden eagles and great blue herons), and numerous types of trout. The loss or disruption of habitat could result in population decreases though no definite studies have been done. A case in point is the necessary selection of flat areas for well and plant sites. Unfortunately, this type of area is the best for deer browsing. This causes a dispersal of the deer population. The increased siltation arising from the accelerated erosion is a second example, in this case affecting the spawning and feeding areas of the native trout.[20] Any water diversion from these low volume streams in late summer could also affect the fish populations.

Water Pollution

The water resources of the region are the subject of concern at The Geysers. The surface waters escape direct pollution from the geothermal operation. The heat is disposed of in cooling towers, while the remaining effluent is reinjected into the earth. Spills of drilling muds have occured in the past resulting in fish kills in Big Sulfur Creek.[15] These mishaps are rare yet warrant utmost care in the handling of wastes, especially during drilling.

An indirect impact of geothermal development on surface waters is through increased sediment load, a result of the surface disturbances and increased erosion. This is a definite factor affecting water clarity and thus fish populations.

The subsurface waters, too, escape possible impacts. The ground water aquifers do not get contaminated by the geothermal steam, or by the reinjected waste fluids. If hot water, instead of steam, is encountered during drilling, the wells are shut in. During reinjection the gravity head literally sucks the wastes down into the non producing well.[20]

Geologic Hazards

Seismic activity is an aspect which causes concern in the development of geothermal resources. Seismic and geothermal phenomena are related, both resulting from unstable conditions in the earth's crust. Micro-earthquakes (below 4.0 on the Richter Scale) occur frequently at The Geysers but have shallow focal depths and are not considered serious. The connection between these and larger quakes is not known however. Only three earthquakes in excess of 4.0 on the Richter Scale have occured in the immediate vicinity since 1934. No damage to any of the operating units at The Geysers has resulted.[12]

The current practice of waste fluid reinjection heightens the concern. Seismic activity has accompanied fluid injection done to repressurize oil fields. Unlike oil fields, geothermal reservoirs exist at sub-

normal pressure and reinjection does not raise the pressures above their original levels. Seismic activity is not triggered by reinjection.[4]

Another geologic hazard is land subsidence. However, no subsidence has occurred at The Geysers, nor at Larderello, Italy, in the more than 60 years of production there.[4] Dry steam fields are capped by low permeability rocks which capably hold steam under high pressure and are not affected by removal of the vapor.

Noise Pollution

A further environmental consideration at The Geysers is noise. Noise levels associated with drilling, well testing, and bleeding (a process of maintaining steam flow through a small opening when the well is not in use) are the most severe. At close range, 25-50 feet, the level contributed by each of these sources approaches or equals the pain threshold of 120 decibels.[20] Drilling continues for 30-45 days per well, the noise levels for total field development would continue over a long period of time. Mufflers are installed on the wells once they are in operation, but it is not possible to muffle the process totally before that point.[4]

There are no residential areas in close proximity to the power generating sites and according to Harry Bain, the sound does not travel far due to the muffling qualities of the valley sides.[3] The sounds could still be a nuisance to people in the area as well as a potential health hazard to workers. The workers do wear ear plugs and muffs for protection.

Other contributions to the noise level result from increases in transport vehicles necessary for generating operations.

Air Pollution

A rather serious impact at The Geysers is gaseous emissions. Many non-condensible gases are carried in the steam though they comprise less than 1% of the steam by weight.[1] No oxides of nitrogen, smoke, fly ash, or other aerosols are produced as in fossil fuel plants. Also, the level of radioactivity of gases in the steam is at or very near background radiation level.[4]

The gas creating the most noticeable affect is hydrogen sulfide, H_2S, the "rotten-egg" gas. California Air Resources Board (CARB) allows .03 ppmv in ambient air and the Northern Sonoma County Air Pollution Control District limits point source emissions to 1000 ppmv.[19] Toxic effects begin on human beings at 10 ppm.[20] The CARB standard is nearly equal to the odor threshold for H_2S. In other words, if one can smell H_2S the CARB standard has been exceeded. This is a frequent occurrence at The Geysers.[1] The Geysers' steam carries an average of 223 ppm of H_2S by weight before going through a gas ejector system and the cooling tower. The point source emissions at the cooling towers range from 1 to 12 ppmv. This is well below the permissible point source levels, but the effects of H_2S are additive and to maintain ambient standards these should be reduced.[1]

PG&E is currently working to improve the abatement of H_2S. By the summer of 1977 a backfitting of the older units with an "iron catalyst" abatement system will be completed. This will reduce H_2S emissions by 50% to 850 lbs/hour. Some of the generating plants currently under construction are being fitted with the Stretford abatement system, potentially reducing emissions by 90% with an end product of elemental sulfur.[17]

Over time a decrease occurs in the concentrations of non-condensible gases emitted from wells that have been producing for several years.[9] This drop in individual well emissions will probably not result in a

change in total emissions, since it will be offset by current and planned expansion. The total emissions will stay fairly constant but affect a larger area, thus they can not be overlooked.[19]

Another impact resulting from geothermal development is the heat factor. Since geothermal plants give off great quantities of heat through their cooling towers, it has been thought that local weather patterns may be affected. Climatological evidence does not bear this out. No changes in the weather pattern have been observed.[15]

The Geysers area is one of high scenic value, one which is adversely affected by surface disruptions like roads and power facilities. Hamilton Hess, a Sierra Club spokesman, recommends government supported research to develop a system for underground or concealed installation of well heads, pipelines, and transmission lines. He also advocates "judicious siting and reduction in size of drilling pads" along with effective replanting.[11] These concerns are not totally being overlooked. Attempts are being made to blend pipelines and structures more with the foliage and soil. As mentioned above replanting is being carried out.[6]

Environmental impacts are a concern for the area because of its recreation uses. The scenic Sonoma-Lake Counties area is a favorite hunting, fishing, hiking, and general outdoor recreation spot. Recreation is obviously greatly impaired near the geothermal developments. Quality is not the only concern; public access is restricted on much of the developed land. The land use question is a major one because geothermal development is at least a 30-50 year land commitment.[20]

TRENDS

Concerning the planning of future development of electrical generation facilities at The Geysers, under the current California Public Utilities Commission regulations, utility companies are required to submit applications for plant sites one year in advance of commencing construction, which in practice means about four years before anticipated operation. The required steam supply, moreover, must be available for about one year to allow for pipeline construction. Thus, allowing time for evaluation subsequent to discovery, a lead time of five years between confirmation drilling and commercial operation is required.[5] These delays tend to lower PG&E's rate of return on their investment, which is eventually passed on to the consumer in the form of higher rates for electricity.

At present, PG&E believes that there is a large potential at The Geysers - they envision an approximate four-fold increase over present production, with gradual expansion every year. By 1980, they plan to have enough facilities to generate 908,000kW. By 1983, they expect to be generating 1,568,000kW, and by 1986 they plan to be generating approximately 2,000,000kW of electricity.[7] The entire energy demands of the San Francisco Peninsula could be supplied by 2,500,000kW.[14] PG&E is actually bound by contracts for expansion - their steam supply contracts with the independent suppliers state that PG&E must install an additional generating capacity of 100,000kW per year provided sufficient steam is made available. This is to insure the security of the companies that are exploring for and supplying the steam.

Performance records of individual wells at The Geysers Field have shown that a constant rate of steam production cannot be sustained for an indefinite time. Individual wells have declined in production, and additional wells have been drilled to maintain the supply of steam to the generating units. The decline in pressure of individual wells is due to particulate matter in the steam which gradually seals up the frac-

ures in the rock immediately surrounding the well, thereby impeding the movement of steam.[5] Koenig (1971) as estimated the individual well life to be approximately ten to fifteen years, and he believes the field ife of The Geysers is around thirty years. The United States Geological Survey also estimates the field ife to be thirty years, based on 1,600,000kW continuous production. The current feeling of PG&E and Union il (the major steam supplier) is that a thirty year field life estimate is conservative. Since production egan in 1960, there has been less than a 1% decline in pressure over The Geysers Field as a whole. Union il's confidence is exemplified by their plans to be supplying enough steam to generate 2,000,000kW by 1986, nd still fulfill their contract obligation to maintain the supply of steam to the electric power generation nits for thirty years.[3]

No one is certain about the recharge rate of the geothermal dry steam reservoir. PG&E is currently re-injecting used condensed steam via abandoned wells, but the effect of this has not been determined. If rtificial injection proves possible and feasible in the future, however, perhaps the field life of The Geysers will be considerably extended.

SOCIO-ECONOMIC IMPACTS

One of the most critical factors in the expansion of geothermal facilities is the current opposition by the residents of south-western Lake County. Opposition has been mobilizing against geothermal develop-ment because there is no land use plan for development in the county, and therefore residents fear that economics will rule geothermal development, with no consideration for the quality of life and no protection for sensitive ecological areas. Moreover, the residents feel that existing environmental regulations, such as those setting maximum H_2S emission, are being ignored or are not being properly implemented. Although existing geothermal development is mainly in Sonoma County, it can be seen from the KGRA maps that the majority of the future geothermal electrical generation potential of The Geysers is in Lake County.

Lake County is a low density, low income, retirement and recreation area. Clear Lake is the main focus of recreation, and there are various types of orchard farming in the area. In addition, the majority of the Lake County population resides in the Clear Lake Basin. Conflicts are certain to arise as geothermal development and the accompanying noise, visual, and air pollution moves closer to the basin.

Problems of this sort have already begun. An example is the development on Cobb Mountain, which is right on the Lake-Sonoma County border. A beautifully-forested area, it serves primarily as a recreation area and as the home for numerous retired people. Residents and visitors are already complaining about the noise and air pollution from current generating facilities at The Geysers. Just recently a well was drilled in the Cobb Mountain ridge, the first well in Lake County. It is the most productive well drilled to date, and the independent steam developers believe there is similar potential on Cobb, less than one mile away. The decision of what is more important, the happiness of local residents or more electricity for California, will be a tough one to make.

CERCDC believes that there will be other socio-economic impacts with future geothermal development in Lake County, as a result of more people, industry, and dollars.[7] Residents are concerned about the ability of Lake County to handle industrialization and resulting growth, and the ability to maintain their present life style. However, industrialization and growth has not been the case in northern Sonoma County, and solid facts about the potential effects on the economy of Lake County are hard to find. Harry Bain states

that the increase in tax revenues from The Geysers in Sonoma County was $2.2 million in 1975, $3.5 million in 1976, and will be $4.5 million in 1977, an increase of approximately 30% per annum.[3] When the new 135,000kW generating plant is built in Lake County, tax revenues from it are expected to be $1.0 million in 1978. This is not a significant amount, however, compared to the present tax bases of the counties. It does seem clear that Lake County residents are sufficiently concerned about the future of their area that any increase or acceleration of geothermal development at The Geysers will be met with stiff citizen opposition unless the aforementioned concerns are alleviated.

CONCLUSIONS

Three aspects interplay to determine the feasibility of geothermal energy development: economics, and social and environmental impacts. The economics of geothermal energy do make it an attractive baseload source which will look better in the future as other fuel costs increase. It is not an environmentally clean solution, but impacts remain low compared to fossil fuel sources. Since the effects are localized, they are heavily felt in the resource area. Improvements to minimize impacts are being worked on and could definitely increase the acceptance of geothermal development. In addition, the social picture must be considered, how the area residents and users are affected. Their concern about quality of life and experience is hard to measure but must not be overlooked. A balance between these three main areas must exist, with improvements made through fuller research, planning, and assessment in the future.

In the absence of a panacea energy source, all possible sources must be evaluated. Given the resources, geothermal energy is a viable source for the Bay Area, at least in the short term. It can never prove to be a universal solution to energy problems but is supplementally useful on a localized scale. The Geysers power producing facilities have proven that, and fuller development, if environmental and social considerations warrant it, can contribute a larger portion to the Bay Area electricity supply. This would alleviate some of our dependence on fossil fuels and be attractive both in the conservation frame and in terms of moving toward fuller development of domestic sources, decreasing the dependence on foreign resource supplies.

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