ENVIRONMENTAL EFFECTS OF GEOTHERMAL POWER

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Contents

Summary

Although geothermal energy offers many environmental advantages over traditional fuel sources, it is important to remember that geothermal resources are found in diverse environments that require assessing the potential impacts of each project individually. Geothermal power is a relatively benign source of energy. For the most part, the impacts of development are positive. Minor environmental impacts are seen in certain specific areas, but mitigation measures exist for all known adverse impacts. Any large-scale construction and drilling operation produces visual impacts on the landscape, creates noise and wastes, and affects local economies. Environmental issues usually addressed during the development of geothermal fields include air quality, water quality, waste disposal, geologic hazards, noise, and biological resource and land use issues.

Based on the discussion presented in the following sections, the major advantages to using geothermal resources as a major source for electrical generation can be summarized as follows:

- Surface water resources are rarely significantly impacted by geothermal development because an external water source is not required under normal operating conditions at most geothermal development sites.
- Air emissions from geothermal power plants are significantly less than from power plants using conventional fuel sources, particularly for critical noncondensable gases such as hydrogen sulfide and carbon dioxide. Increased releases of these gases contribute greatly to the greenhouse effect and to other forms of environmental degradation.
- Wastes from geothermal projects are minimal when compared with those produced by other fuel sources. The type of wastes generated depend strongly on the physical characteristics of the resource and the type of conversion technology used.
- Land disrupted by geothermal power plant development is much less than that required for other energy sources.

1. Geothermal Systems

1.1. Introduction and History

Most prevalent in regions of elevated heat flow and vigorous fluid circulation, geothermal systems occur wherever reservoirs of hot water and steam exist at comparatively shallow depths. These systems occur along or near convergent plate margins, near transform plate boundaries, within spreading centers and rifts, and within hot spots. Geothermal systems commonly produce hot springs and fumaroles as surface expressions of underlying hot reservoirs. Hot and mineral springs have been valued for their therapeutic qualities. Hot springs and fumarole areas have been exploited for sulfur and other minerals. During the Middle Ages, the commercial value of Italian hot spring deposits led to wars among local republics. Electricity was first produced from a steam well at Larderello, Italy, in 1904, and commercial electricity was first marketed in 1913. Since that time, geothermal power has been developed by many countries as an alternative to burning imported or domestic fossil fuels. Commercial geothermal fields produce electricity by piping extracted hot fluids from wells to turbine-driven generators. The focus of this paper is on high-temperature (≥200°C) geothermal systems and flashed steam and dry steam power plants, which represent the majority of current generating facilities.

1.2. Resource Locations and Characteristics

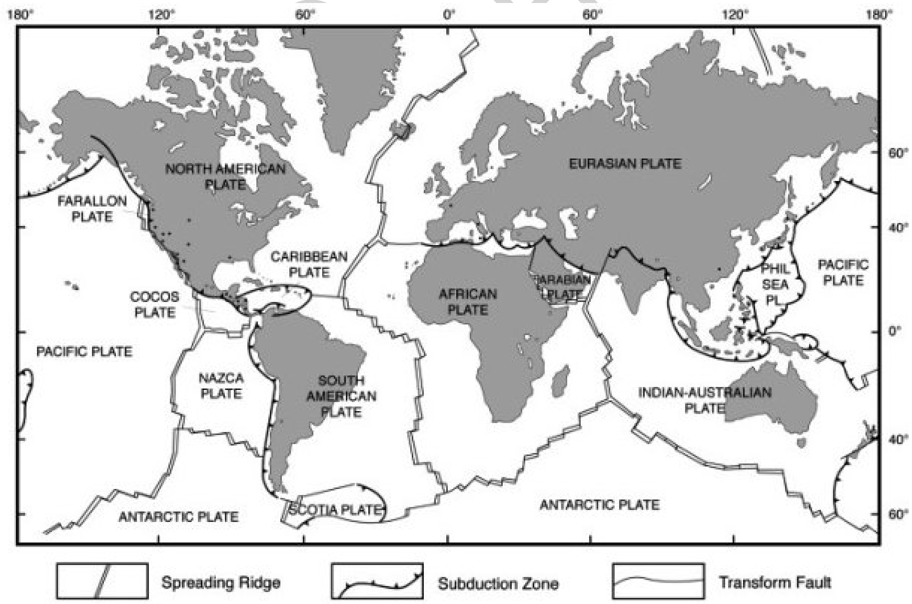

Figure 1. Distribution of geothermal resources around the world

Geothermal resources are not distributed evenly around the globe (Figure 1), and certain regions are blessed with resources while others are relatively barren. It is not surprising that the ten leaders in generating electricity from geothermal resources (Table 1) are in areas of active volcanism. Today, about 8000 MW of electrical power (the equivalent of

80 million barrels of petroleum annually) are produced from geothermal systems worldwide. Most geothermal systems are liquid-dominated.

Liquid-dominated reservoirs have maximum temperatures of ≤370°C and have widely ranging salinities. When fluid is produced from wells, it must be depressurizd (flashed) to produce steam for the turbines. This is done under controlled conditions with large steam separators. Approximately 80% of the fluid is liquid water that must be disposed, usually by reinjection. As steam separates, noncondensable gases, such as CO_2, H_2S, and NH_3, partition into the steam phase, and the residual brine becomes more concentrated in most chemical species.

Country	**Electrical (MWe)**[b]	**Country**	**Direct Use (MWt)**[c]
United States	2850	United States	2000
Philippines	1780	China	1914
Mexico	743	Iceland	1443
Italy	742	Japan	1159
Indonesia	589	Hungary	750
Japan	530	Italy	314
New Zealand	364	France	309
El Salvador	105	New Zealand	264
Nicaragua	70	Georgia	245
Costa Rica	65	Russian Federation	210
Total of Leaders	7838	**Total of Leaders**	8608
Total Worldwide	8029	**Total Worldwide**	9963
Leaders (percent)	98	**Leaders (percent)**	86

a. For electrical generation and direct-use applications.
b. MWe = megawatts electrical.
c. MWt = megawatts thermal; 1 MWe ≈ 7MWt.

Source: Goff, F., and C. J. Janik, in press. “Geothermal Systems, Encyclopedia of Volcanoes, (B. Houghton, H. Rymer, J. Stix, and S. McNutt, Eds.), Academic Press, Inc., Chapter 51.

Table 1. Ten World Leaders in Installed Geothermal Capacity[a] (Late 1998)

In addition to liquid-dominated reservoirs, there are vapor-dominated reservoirs. Vapor-dominated reservoirs are the most prized because, in contrast to liquid-dominated reservoirs, virtually all produced fluid is piped to the power turbines. Only five such systems are known: Larderello (Italy), The Geysers (USA), Matssukawa (Japan), and Kamojang and Darajat (Indonesia).

These five fields contain about 35% of the world’s geothermal electrical capacity. The Geysers, the world’s largest commercial geothermal system, produced a maximum of about 1700 MWe in the mid-1980s. Figure 2 shows power generation schemes for both liquid- and vapor-dominated reservoirs.

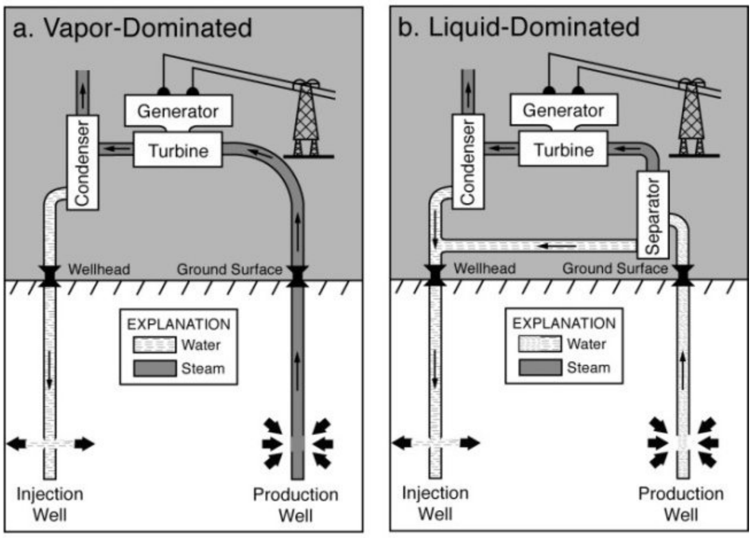

Figure 2. Power generation schemes for liquid- and vapor-dominated dominated reservoirs.

There are five principal types of geothermal systems, based on geologic, geophysical, hydrologic, and engineering criteria. The first three types—young igneous systems, tectonic systems, and geopressured systems—exploit natural reservoirs of hot water and are generically called hydrothermal systems. The second two types—hot dry rock and magma tap—require pumping a fluid, generally water, into the ground and then out again to extract heat. Technically feasible under certain conditions, these two systems are commercially impractical under current economic conditions.

1.2.1. Young Igneous Systems

Young igneous systems are associated with Quarternary volcanism and magmatic intrusions. About 95% of volcanic activity occurs along plate boundaries and within hot spots. Such environments are usually associated with major tectonic activity and seismicity. Fluids derive their heat from the margins of crystallizing or recently crystallized magma. These geothermal systems are generally the hottest (≤370°C), and reservoir depths are commonly ≤1.5 km.

1.2.2. Tectonic Systems

Tectonic systems are those that have elevated heat flow but that are essentially devoid of igneous activity. They occur in back-arc environments, regions of crustal extension, collision zones, and along faults zones of any displacement or length. Tectonic systems are usually associated with elevated seismicity due to Quarternary faulting and with elevated heat flow due to thin crust. Deep circulation of fluids into the crust and ascent of these fluids along faults move heat upward into favorable geologic structures. Tectonic systems capable of generating electricity usually have reservoir temperatures ≤250°C and occur at depths ≥1.5 km.

1.2.3. Geopressured Systems

Geopressured systems are found in sedimentary basins where subsidence and deep burial of fluid-bearing strata have formed hot, "over-pressured" reservoirs. Wells drilled into geopressured reservoirs exhibit very high artesian pressures. Heat flow and seismicity range from comparatively low to normal. Most systems of this type have characteristics resembling oil and gas fields. Geopressured systems often require deeper drilling than young igneous and tectonic systems. Typical depths and temperatures are 1.5 to 3 km and 50°C to 190°C.

1.3. Outline of Environmental Issues

Geothermal power is a relatively benign source of energy. For the most part, the impacts of development are positive. Worldwide geothermal energy utilization increases yearly because it is an attractive alternative to burning imported and domestic fossil fuels. However, geothermal development could have certain negative impacts if appropriate mitigation actions and monitoring plans are not in place. Any large-scale construction and drilling operation will produce visual impacts on the landscape, create noise and wastes, and affect local economies. Some countries have strict environmental regulations regarding some of the impacts associated with geothermal development, and others do not. Environmental issues usually addressed during the development of geothermal fields include air quality, water quality, waste disposal, geologic hazards, noise, biological resources, and land use issues.

2. Air Quality

2.1. Introduction

Air quality impacts from geothermal development depend on the chemical composition of the geothermal steam, existing air quality, baseline meteorological conditions, resource temperature, resource type (steam, two-phase, hot water), terrain, and number of geothermal emission sources and their spatial and temporal distribution.

2.2. Air Quality of Geothermal Plants Compared with Fossil Fuel Power Plants

There are several significant differences between air quality issues of geothermal power plants and those of conventional power plants. The differences include the extent of particulate emissions, generation of acid rain, and contributions to global warming. Fossil-fuel power plants using wet cooling towers have significantly greater particulate emissions when they use make-up water high in total dissolved solids (TDS). Because geothermal power plants use low-TDS condensed steam for cooling tower make-up water, the resulting particulate emission rates from geothermal cooling towers are very low. Geothermal power plants also have lower total sulfur emissions than their fossil fuel counterparts. Studies from The Geysers geothermal field in California have shown that no acid rain effects are occurring in that region. Compared with fossil-fuel power plants, the geothermal plant itself emits no nitrous oxides or sulfur oxides and only relatively small quantities of CO_2. In most hydrothermal systems, noncondensable gases make up less than 5% by weight of the steam phase (Table 2). Carbon dioxide is the dominant (over 90% by weight) constituent of these gases. Hydrogen sulfide (H_2S), sulfur dioxide, ammonia, and methane are the other common gases. For the same output of electricity, carbon dioxide emissions from geothermal flashed-steam power plants are only a small fraction of emissions that result from burning hydrocarbons. For each megawatt-hour of electricity produced in 1991, the average emission of carbon dioxide by plant type in the US was 990 kg from coal, 839 kg from petroleum, 540 kg from natural gas, and 0.48 kg for geothermal flashed steam.

Location	**Total Dissolved Solids (ppm)**	**Noncondensable Gas (by weight)**
Coso, California	5300–6500	2%
The Geysers, California	4–430	1.7%–15%
Imperial Valley, California	16,000–250,000	1.6%–6%

*****Source: Brophy, P., 1997. "Environmental Advantages to the Utilization of Geothermal Energy," *Renewable Energy*, **10,** Nos. 2 and 3, 367-377.

Table 2. Physical and Chemical Characteristics of Selected Geothermal Resources*

2.3. Hydrogen Sulfide Emissions

Hydrogen sulfide (H_2S) is the gas of primary concern in geothermal reservoirs. Hydrogen sulfide is a noxious gas that is immediately dangerous to life and health at levels of about 142 mg/m H_2S of air. The amount of H_2S in geothermal resources varies. Hydrogen sulfide can reach moderate concentrations in steam produced from some geothermal fields, and some systems contain up to 2% by weight of H_2S in the separated-steam phase. At low concentrations, H_2S can cause an odor nuisance. At higher concentrations, H_2S is acutely toxic. The average human nose can detect as little as 20 ppb H_2S.

2.3.1. Points of Release

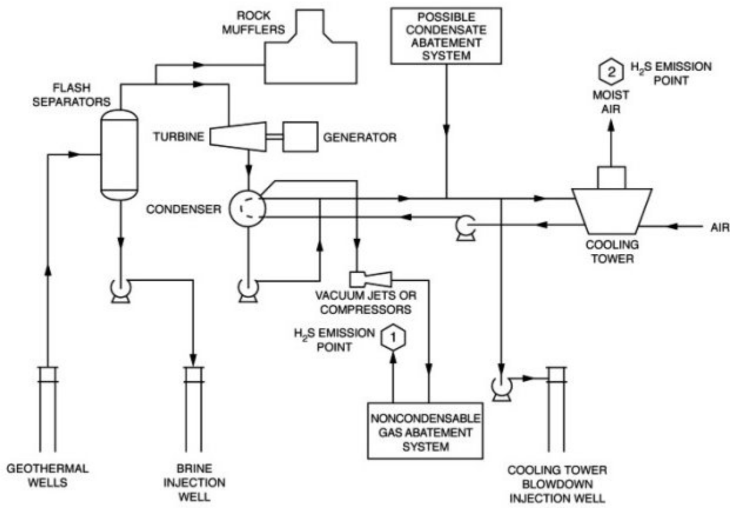

Figure 3. Generalized system flow diagram.

During well drilling and testing, potential points of release for H_2S at any geothermal project include steam venting during power plant start-ups and shut-ins and wells on bleed, and, during normal power plant operations, condenser off-gas, cooling tower drift, and fugitive emissions. Figure 3 presents a generalized system flow diagram outlining potential H_2S emission points.

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Biographical Sketches

Ms Sue Goff has worked in Latin America since 1986. As Project Leader for the Geothermal Resources Assessment Component of the US Agency for International Development funded Central American Energy Resource Evaluation Project, she designed, organized, and managed successful prefeasibility operations in rural Honduras and Guatemala. She has excellent language skills, and speaks and reads

Spanish. She has traveled extensively, primarily to the developing world (Honduras, Guatemala, El Salvador, Costa Rica, Indonesia, China) to present the results of her work. She has consulted for the University of Nevada, serving as the liaison with the Guatemalan government for a team investigating the Zunil, Guatemala landslide and for the InterAmerican Development Bank, reviewing the environmental impacts of planned geothermal development projects in El Salvador. She has assisted the Honduran government with their geothermal energy development plans and negotiated an agreement with the Honduran utility to co-share the costs of continued pre-feasibility work at the Platanares site. She has recently developed a plan, based on her work, for feasibility studies of geothermal sites in Honduras and Guatemala in response to the need for rebuilding Central America in the aftermath of Hurricane Mitch. She is the DOE representative on an IEA implementing agreement on the Environmental Impacts of Energy Development. She is the 1st Vice President of the Geothermal Resource Council, Chair of the newly formed External Liaison Committee, member of the Advisory Committee. In addition, she is a member of the Board of Directors of the International Geothermal Association and the Chair of the By-Laws Committee.

Paul Brophy has worked extensively in the resource assessment and environmental permitting of geothermal projects worldwide. He was a presenter at the National Geothermal Association (now Geothermal Energy Association) Workshop on Geothermal Energy in Costa Rica in 1993 and a delegate on the US Department of Energy Mission to that country in 1995. He has also made presentations at an International Conference on Environmental Issues in Peru and at a United Nations Regional Seminar held in Santiago, Chile in 1995. Mr Brophy was the original Project Manager for a four-year World Bank funded project to provide environmental technology transfer services to the Philippine Department of Energy. This project invoved the establishment of a national environmental framework for future geothermal energy development. Most recently he has been Project Manager for the exploration phase of geothermal resource development on the island of St. Vincent in the Caribbean. Mr Brophy has worked in the geothermal industry for over 18 years and is currently on the Board of Directors of The Geothermal Resources Council and Chairperson of the Membership Committee.

During his Ph.D. program, **Dr. Fraser Goff** was employed by the U.S. Geological Survey as chemist and geologist in evaluation of The Geysers-Clear Lake geothermal region, California. His major research efforts over the last twentyfive years include : the evaluation of both conventional and hot-dry-rock geothermal resources through integration of geological, geophysical, and hydrogeochemical data; field-oriented geologic, petrologic, and hydrogeochemical studies of Quaternary-Tertiary volcanic provinces; and application of hydrogeochemical techniques in geothermal, volcanological, and environmental research. He was Task Manager of the US hot-dry-rock resource evaluation and site assessment team (1980-1982). He planned much of the coring strategy for three exploration holes in Honduras and one in Guatemala (1986-1990). He has worked on 30 geothermal systems in the USA and ten countries. He has investigated the hydrogeochemistry of geothermally-connected oil fields in the Great Basin, Nevada. He leads a small team investigating environmental isotopes in groundwaters within LANL property and mercury transport from mine tailings in California. He has worked on 14 active volcanoes studying magmatic volatiles (1985-present) and has recently been involved with a project to develop new remote sensing techniques for measuring volcanic plume compositions and flux. He has recently participated in a small project to investigate the CO_2-sequestering potential of ultramafic rocks. He is Adjunct Professor at the University of New Mexico and is a Fellow of the Geological Society of America.