Clearing the Air

Air Emissions from Geothermal Electric Power Facilities Compared to Fossil-Fuel Power Plants in the United States

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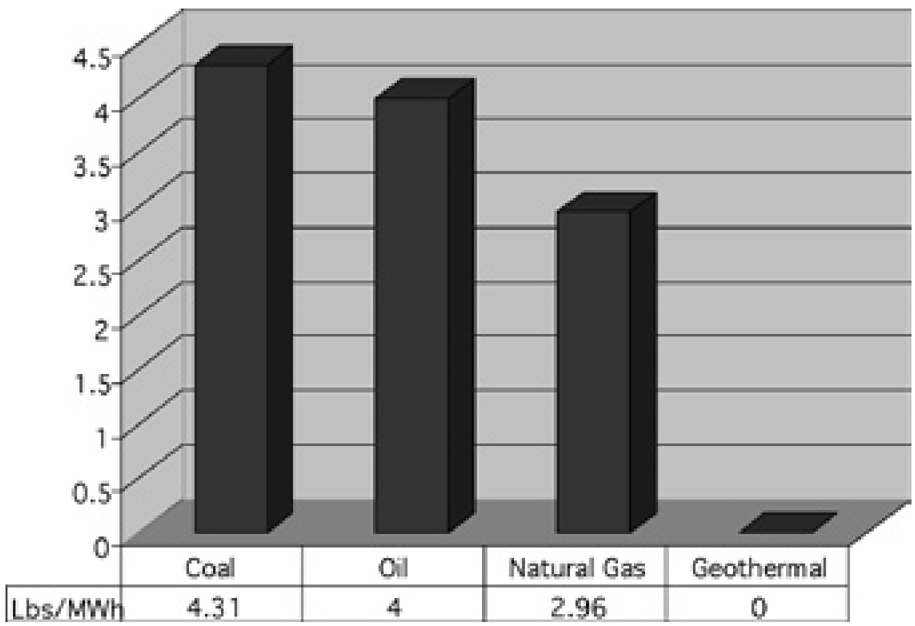
Editor's Note: The following article is an edited version of "Air Emissions from Geothermal Electric Power Facilities," submitted and accepted for publication in Vol. 29 of the GRC *Transactions*, and presentation in the Barriers to Geothermal Development Session at the GRC 2005 Annual Meeting, on Sept. 25-28 in Reno, NV.

The Geothermal Energy Association (GEA – Washington, DC) recently assessed the inadequacy of available geothermal environmental literature, especially regarding environmental issues. This article brings together the most current geothermal and fossil-fuel emissions data, providing details and analyses of emissions from nitrogen oxides, hydrogen sulfide, sulfur dioxide, carbon dioxide, and mercury. When compared to fossil-fuel energy sources such as coal and natural gas, geothermal—a combustion-free renewable electricity source—emerges as one of the least polluting forms of energy, producing near-zero air emissions.

Overview

In May 2004, GEA completed an extensive literature review of the environmental, socio-economic and technological information publicly available about geothermal energy. This review was conducted in response to concerns that there was a lack of accurate, up-to-date information about this renewable energy source. That assessment found that the available literature was seriously inadequate, often providing outdated or false information. For those interested in this review, GEA published its assessment of the available literature concerning environmental issues of geothermal energy (1), including air emissions, land use, water quality, and noise pollution. It is available on the GEA website at: www.geo-energy.org, or by request.

Figure 1 – Nitrogen Oxide Comparison



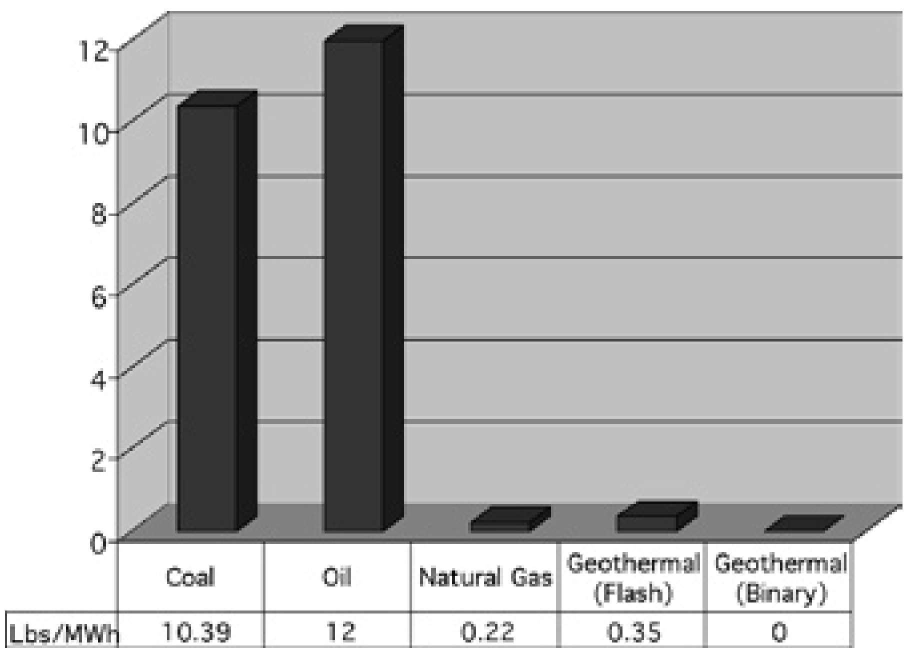
Coal, oil, and geothermal reported as average existing power plant emissions; natural gas reported as average existing steam cycle, simple gas turbine, and combined cycle power plant emissions. Note: While we recognize that recent technological developments result in decreased emissions from some newly constructed fossil fuel facilities, we have elected, in all figures throughout this article, to compare existing geothermal facilities to existing fossil-fuel facilities.

This article provides an abbreviated version of a larger document produced by GEA, also available on the GEA website. Here we document the environmental aspects of geothermal energy, particularly as they relate to high-temperature grade, power-producing geothermal facilities. The following discussion focuses on the air emissions section of the larger GEA document.

Recent Developments

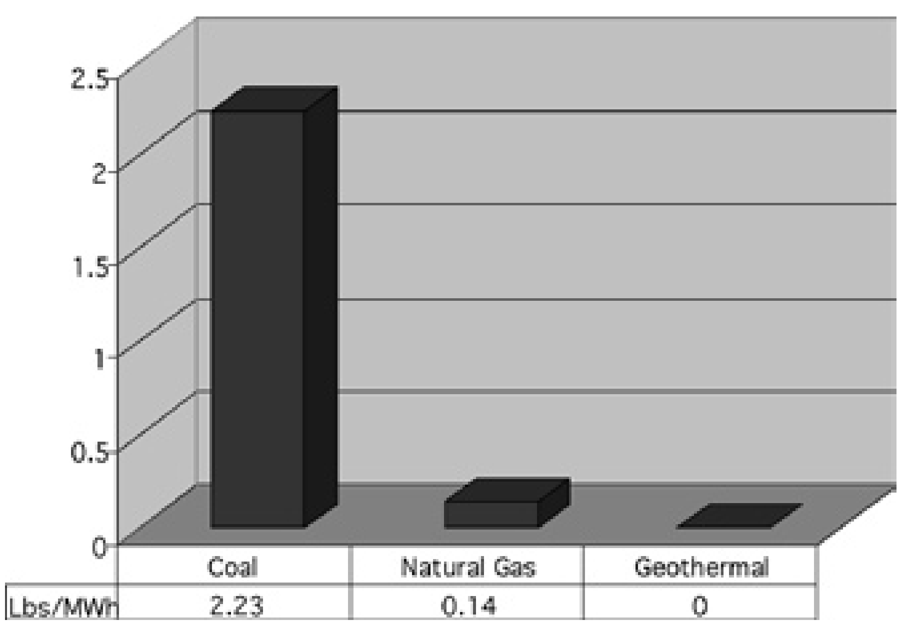
Recent interest in geothermal energy particularly, and renewable energy in general, has precipitated expansion of the geothermal electricity market. The Chena Hot Springs Resort in Alaska will develop its first geothermal power project that pairs the direct use of geothermal energy with on-site geothermal electricity generation; meanwhile, in the next few years, the first geothermal plant will be developed in Ari-

Figure 2 – Sulfur Dioxide Comparison



Coal, oil, and geothermal reported as average existing power plant emissions; natural gas reported as average existing steam cycle, simple gas turbine, and combined cycle power plant emissions. Calculation converts hydrogen sulfide to sulfur dioxide for comparison only.

Figure 3 – Particulate Matter Comparison



Comparing pulverized coal boiler and natural gas combined cycle with an average existing geothermal power plant.

zona. Idaho will soon see its first geothermal power project at Raft River come online, and potentially demonstrate new higher-efficiency power generation technology.

The Nevada Renewable Portfolio Standard is expected to stimulate the production of over 200 megawatts (MW) of new geothermal power, doubling the geothermal generation in the state. Oregon may also see significant growth in geothermal power development, and Hawaii, Washington, Colorado, Montana, Texas and Wyoming are beginning to explore the potential of new geothermal power facilities. These and other developments are expected to add 2,000 MW or more of geothermal power in the United States during the next decade, doubling current geothermal electric production.

Geothermal Power Plant Emissions

One of the most significant benefits of geothermal energy, besides a high capacity factor, is its near-zero air emissions. While variations in geothermal power plant technology and cooling systems can influence emission levels, geothermal energy facilities across the United States comply with all federal standards for air quality, including the more stringent California standards.

Consider the following example. In 2003, Denver's Cherokee coal-fired power plant, which has been retrofitted with scrubbers and other pollution control mechanisms, emitted 23 times more carbon dioxide, 10,837 times more sulfur dioxide, and 3,865 times more nitrous oxides per megawatt hour than the average of eleven geothermal steam plants at The Geysers (2). Air quality statistics for Lake County, downwind of the world's largest geothermal field, The Geysers, highlights the potential benefits of geothermal electricity production. It is the only air district in California that has been in compliance with all state and federal air quality standards for the past 17 years.

The following sections compare and contrast geothermal and fossil-fuel power plants in terms of nitrogen oxides, hydrogen sulfide, sulfur dioxide, particulate matter, and carbon dioxide emissions.

Nitrogen Oxides (NO_x). Because geothermal power plants do not burn fuel, they emit very low levels of NO_x. The small amounts of NO_x released result from the combustion of hydrogen sulfide (H_2S). Geothermal facilities are generally required by law to maintain H_2S abatement systems that capture these emissions, and either burn the gas or convert it to elemental sulfur. During combustion, small amounts of NO_x are sometimes formed, but these are miniscule. Average NO_x emissions are zero (Fig. 1) (3). When comparing geothermal energy to coal, current U.S. geothermal power generation of about 15 billion kilowatt-hours (kWh) reduces NO_x emissions by around 32,000 tons.

Hydrogen Sulfide (H_2S). Identifiable by its distinctive "rotten-egg" smell, H_2S is the pollutant generally considered of greatest concern for geothermal power operations. Since 1976, H_2S emissions from geothermal power plants have declined from 1,900 lbs./hr. to 200 lbs./hr. or less, even though geothermal power production has increased from 500 megawatts (MW) to over 2,000 MW (4). The two most commonly used vent gas H_2S abatement systems are the Stretford system and the LO-CAT. Both systems remove over 99.9 percent of H_2S from non-condensable gases (5), and convert it to elemental sulfur for use as a soil amendment and fertilizer feedstock. Today, geothermal steam and flash power plants produce only minimal H_2S emissions. Binary geothermal power plants release no H_2S emissions at all.

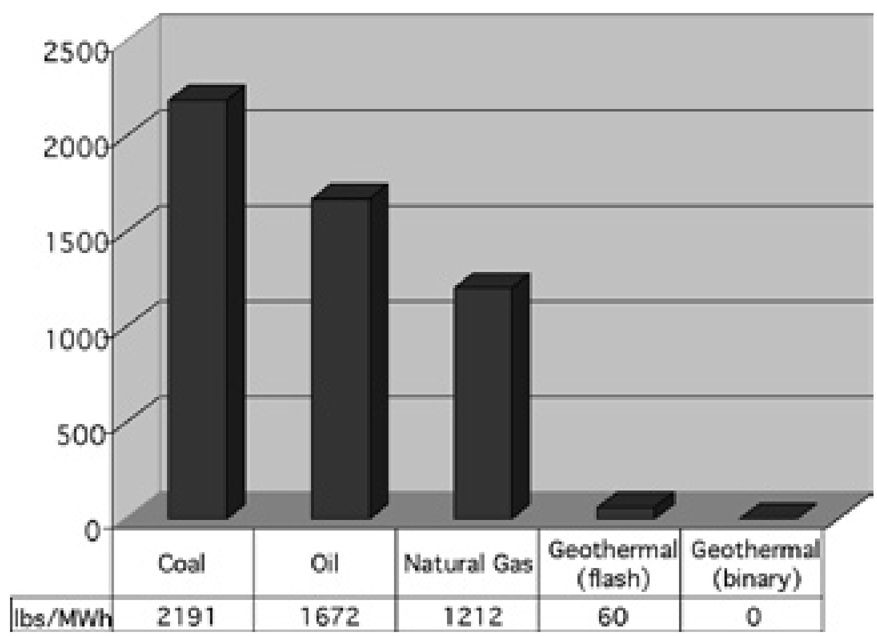
Sulfur Dioxide (SO_2). Geothermal power plants do not directly emit SO_2. Once H_2S is released, it spreads into the air and eventually changes into SO_2 and sulfuric acid (6). When comparing geothermal energy to coal, current geothermal generation of about 15 billion kWh avoids the potential release of 78,000 tons of SO_2 (7). Geothermal power plant H_2S emissions have been converted for comparison purposes to SO_2 in Figure 2 (8).

Table 1 – Air Emissions Summary

Lbs. per megawatt hour:	Nitrogen Oxides	Sulfur Dioxide	Carbon Dioxide	Particulate Matter
Coal (average existing facility)	4.31	10.39	2191	2.23
Coal (with emissions controls, 2003)*	4.02	2.33	2154	n/a
Oil	4	12	1672	n/a
Natural Gas	2.96	0.22	1212	0.14
EPA Listed Average of all U.S. Power Plants**	2.96	6.04	1392.5	n/a
Geothermal (flash)	0	0.35	60	0
Geothermal (binary and flash/binary)	0	0	0	negligible
Geothermal (Geysers steam)	.00104	.000215	88.8	negligible

** Emissions reported for Cherokee power plant, a coal-fired, steam-electric generating station, as provided by Xcel Energy. ** U.S. Environmental Protection Agency (EPA - 2000).* Average Power Plant Emissions from EPA 2000 Emissions Data, *http://www.epa.gov/cleanenergy/egrid/highlights.*

Figure 4 – Carbon Dioxide Comparison



Coal, oil, and geothermal reported as average existing system emissions Natural gas reported as average existing steam cycle, simple gas turbine, and combined cycle system emissions.

Particulate Matter. While coal- and oil-fired power plants produce hundreds of tons of particulate matter annually, geothermal power plants emit almost none, as shown in Figure 3 (9). Water-cooled geothermal power plants give off small amounts of particulate matter from cooling towers when steam condensate is evaporated, but the amount is quite small when compared to coal- or oil-fired power plants. In a study of California geothermal power plants, PM10 is reported as zero (10). It is estimated that geothermal energy produced in the United States prevents the emissions of over 17,000 tons of particulate matter each year when compared to the same amount of power produced by coal-fired power plants (11).

Carbon Dioxide (CO_2). A colorless, odorless gas, CO_2 is released into the atmosphere primarily as a byproduct of burning various fuels. Geothermal steam is generally condensed after passing through the turbine, but CO_2 does not condense, and instead passes through the turbine to the exhaust system where it is released into the atmosphere through cooling towers. Amounts of CO_2 in geothermal fluids can vary depending on location, and the amount of CO_2 actually released into the atmosphere can vary depending on power plant design. This makes it difficult to generalize about the amount of CO_2 emitted by an "average" geothermal power plant. For example, binary plants with air cooling are closed-loop systems and emit no CO_2, because geothermal fluids are not exposed to the atmosphere. Despite these disparities, even the "dirtiest" geothermal power plant will emit only a fraction of the CO_2 emitted by thermal power plants on a per-MW basis. CO_2 emissions from an average geothermal power plant are compared with fossil-fuel power plants in Figure 4 (12). Noncondensable gases such as CO_2 make up less than 5 percent by weight of the steam phase of most geothermal systems (13). Of that 5 percent, CO_2 typically accounts for 75 percent or more of noncondensable gas by volume. Geothermal power production currently prevents the emission of 17 million tons of carbon annually when compared to the same amount of power produced by coal-fired power plants (14).

Mercury. Mercury is not present in every geothermal resource. However, if mercury is present in a geothermal resource, using that resource for power production could result in mercury emissions, depending upon the technology used. In the United States, The Geysers is the main geothermal field known to emit small quantities of mercury, with 80 percent of mercury emissions concentrated at a few facilities where the installation of abatement equipment has been scheduled (15). The Geysers area was mined for mercury from 1850 to 1950, so it is likely that some degree of mercury emissions would exist independently of geothermal development. Furthermore, mercury emissions from The Geysers are below the amount required to trigger a health risk analysis under existing California regulations. Because binary power plants pass geothermal fluid through a heat exchanger, then return all of it to the reservoir, they do not emit mercury. While federal proposals related to mercury risk have focused on coal, state and local governments have also introduced measures to reduce mercury emissions from other sources. As a result, mercury abatement measures are already in place at most geothermal facilities. The abatement measures that reduce mercury also reduce sulfur emissions generated as a byproduct of H_2S abatement (after H_2S is removed from geothermal steam, the gas is run through a mercury filter that absorbs mercury from the gas). The rate of mercury abatement within a geothermal power facility, which varies according to the efficiency of its activated carbon mercury absorber, is typically near 90 percent, and is always efficient enough to ensure that the sulfur byproduct is not hazardous. The activated carbon media is changed out periodically and disposed of as a hazardous waste. The amount of hazardous waste reduction is thousands of tons/year.

Summary and Conclusion

Average air emissions information is summarized in Table 1, along with the average U.S. power plant emissions. The low air emissions from geothermal power facilities are obvious when compared with fossil-fuel power sources.

Despite improvements in coal, natural gas, and oil power plant technology, fossil fuel combustion continues to produce more air pollution than any other single source (16). The U.S. Environmental Protection Agency, in its discussion of power plant impacts, notes that "fossil fuel-fired power plants are responsible for 67 percent of the nation's sulfur dioxide emissions, 23 percent of nitrogen oxide emissions, and 40 percent of man-made carbon dioxide emissions," (17) all of which have been widely documented to cause a host of environmental and health problems.

In light of the inevitable impacts and use of electricity in the United States, and the millions of pounds of emissions released each year from thermal electric generating facilities, comparative power plant emissions data highlights geothermal's ongoing and potential contribution of clean, reliable, and plentiful renewable electricity in the United States and throughout the world. ■

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