Geothermal Energy Reduces Greenhouse Gases

CO_2 Emissions from Geothermal Energy Facilities are Insignificant Compared to Power Plants Burning Fossil Fuels

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This article updates a previous Bloomfield and Moore (1999) estimate of the quantity of carbon dioxide (CO_2), hydrogen sulfide (H_2S), methane (CH_4) and ammonia (NH_3) emitted during geothermal power generation. Since that estimate in 1999, more geothermal power generation capacity has been added in the United States, primarily in the Imperial Valley of southern California. Formal reporting required for fossil-fuel power production provide updated estimates of emissions from generation by those sources.

Greenhouse Gas Emissions and Climate Impacts

For the last century, human activities have been altering the global climate. Observations show that the Earth's surface has warmed by approximately 0.6 °C (1.1 °F) during the 20th century (CCSP, 2003). Atmospheric abundances of the major, human-generated greenhouse gases, i.e. CO_2, CH_4 and nitrous oxides (NO_x), reached their highest recorded levels in modern history by the year 2000 and are continuing to rise. About 37 percent of incremental atmospheric CO_2 accumulation is caused by electric power generation, mainly from the burning of fossil fuels (EIA, 2000).

To counteract these climatic effects, delegations from more than 150 countries met in Kyoto, Japan in December of 1997 to complete negotiations on a United Nations treaty to reduce their emissions of certain greenhouse gases. That agreement—the Kyoto Protocol—calls on developed nations to reduce their use of carbon-emitting fossil fuels. In the United States, CO_2 emissions account for roughly 85 percent of the total for the world. If the Kyoto Protocol is ratified by the U.S. Senate, the United States will have to limit emissions of CO_2 and five other gases by 2008-2012 to 93 percent of 1990 emissions.

This target appears to be fairly modest, at least until U.S. Department of Energy (DOE) projections of energy use and emissions for 2010—based on normal business-as-usual energy and economic growth expectations—are considered. Under this scenario, the United States will have to reduce emissions by nearly one-third of projected emissions to reach the target values (EIA, 2000).

The emissions reduction target is very ambitious, and will require unprecedented action for the United States to get the job done in such a short period of time. It means Americans will have to slash their energy use or select green energy sources quickly and comprehensively (or that production and process efficiencies will have to increase dramatically). The use of geothermal energy can be a significant contributor to reducing energy related CO_2 emissions.

Government Activities

Former U.S. President Clinton issued a directive on April 15, 1999, requiring an annual report summarizing CO_2 emissions produced during electric power generation by both utilities and non-utilities in the United States. In response, DOE and the U.S. Environmental Protection Agency jointly submitted the first report on October 15, 1999 (DOE/EPA, 2000). With two major policy actions, President Bush has also emphasized the importance of technology in stabilizing greenhouse gas concentrations in the atmosphere. The National Climate Change Technology Initiative (NCCTI) announcement on June 11, 2001 included tax incentives for energy efficiency improvements and renewable technologies for buildings, light-duty vehicles and electric generation. To improve research support for decision making and to increase accountability, President Bush

Table 1. Comparison of Geothermal and Fossil Fuel CO2 Emissions.

	Geothermal	Coal	Petroleum	Natural Gas
Emissions (lbs. CO2/kW-hr)	0.20	2.095	1.969	1.321

Table 2. Geothermal "Greenhouse Gas" Emissions

	CO2	H2S	CH4	NH3
Emissions (lbs./kW-hr)	0.20	1.87E-04	1.66E-03	1.39E-04

announced on Feb. 4, 2002, the establishment of a new, high-level structure for coordinating federal climate change science and technology development.

Geothermal CO_2 Sequestration and Government Activities

The federal government has funded a number of activities to investigate sequestration of CO_2 created by electric power generation. The Integrated Sequestration and Hydrogen Research Initiative is a $1 billion government/industry partnership to design, build and operate a nearly emission-free coal-fired electric and hydrogen production plant. The 275-megawatt (MW) prototype plant will serve as a large-scale engineering laboratory for testing new clean power, carbon capture and coal-to-hydrogen technologies.

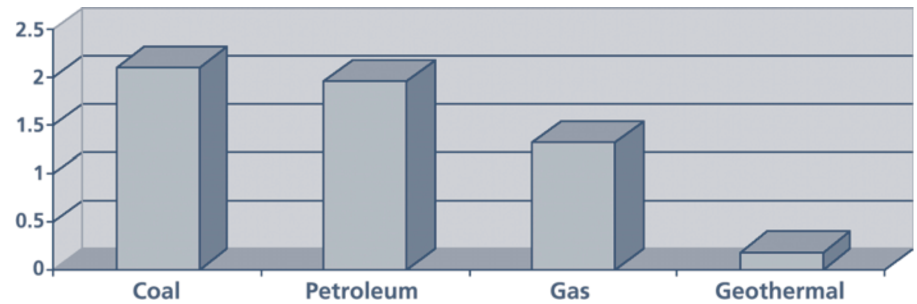
The experience of geothermal plant operators with non-condensable gas injection into their reservoirs is relevant to CO_2 sequestration research and development (R&D). Coso Operating Co. (China Lake, CA) has experimented with injecting or sequestering non-condensable gases mixed with spent geothermal fluids. Operationally, the injection of non-condensable gases met with partial success. The gases communicated very rapidly with some production wells, but not at all with others. Also, corrosion of injection well tubulars increased with the water/gas mixture.

Although there are no engineering barriers to injection of CO_2 into geothermal reservoirs, careful placement of CO_2 injectors that will not communicate with geothermal fluid production wells is essential. Water injection is critical to reservoir management to sustain fluid production. It is apparent that CO_2 and water cannot be injected into the same well. Therefore, a compression and transport system is needed to move CO_2 to non-communicating wells, and premium construction materials may be needed due to corrosion considerations.

U. S. Geothermal Greenhouse Gas Emissions

The most commonly cited reference on gaseous emissions from U.S. geothermal power plants was written by Goddard and Goddard (1990), which determined emissions based on data from utility

Figure 1. CO2 emissions (lbs. CO2/kW-hr).



power producers. This data was mainly gathered at The Geysers in northern California, because Pacific Gas & Electric owned the power plants at the time. However, in estimating geothermal emissions it is important to consider both utility and non-utility power operations, and the mix of dry steam, flashed steam, and binary technology facilities.

More importantly, improved and increased injection to sustain reservoir resources has diminished the CO_2 released from geothermal power plants. Benoit and Hirtz (1994) reported that CO_2 emissions from the Dixie Valley geothermal plant in northern Nevada had decreased from 0.152 pounds of CO_2 per kilowatt-hour (kWh) of electricity produced in 1988 to 0.093 lbmCO_2/kWh in 1992.

Steam that feeds dry-steam and flash-steam plants can contain several weight-percent of non-condensable gases. In these plants, gases contained in reservoir fluids pass through turbines with the steam—but unlike the steam, the gases do not condense at the turbine exhaust outlet. These non-condensable gases are either exhausted to the atmosphere or to a primary abatement system where H_2S is removed. The quantity of gases present in the geothermal fluid and subsequently emitted depends on several factors, including the characteristics of the resource (dry steam or liquid, reservoir fluid composition, temperature), the method of electrical generation (flash, binary, or combined cycle), and plant characteristics (efficiency and H_2S abatement equipment). Binary power plants release no non-condensable gases because their geothermal fluids are not exposed to the atmosphere (Blaydes, 1994).

There are no federal emission limits for CO_2 Under the Clean Air Act of 1990. Consequently, formal reporting of CO_2 emissions is not required by regulatory agencies, denying such data for geothermal power plants to the public domain. Regulatory agencies commonly require an emission source compliance test for other gases, however, including H_2S, NH_3 and CH_4. Data on CO_2, CH_4, NH_3 and H_2S emissions presented here were obtained from geothermal power plant operators, utilities, and state air-quality control boards. The primary sources of electrical production and CO_2 emissions data for this article were operators of geothermal dry steam and flash plants.

Measurement of non-condensable gases in geothermal fluids is critical during initial well testing for power plant design and regulatory concerns. Non-condensable gas content is a major factor in designing condensers, non-condensable gas ejector systems, and H_2S abatement systems for geothermal power plants. Non-condensable gases can be a major regulatory and permitting concern that may result in large capital and operational costs.

Although there is no legal requirement for the collection of CO_2 emission data, it is collected during required compliance tests for regulated emissions. Since production of non-condensable gases is often used as a reservoir monitoring tool and an indicator of power plant energy conversion efficiency, CO_2 data may also be collected during operations. Data supplied by power plant operators included total steam flow to the plant in mass per hour; the mass ratio of steam to total non-condensable gas; net capacity of the plant in MW; and concentrations of gaseous components.

Several assumptions were made in performing emission calculations. It was assumed that CH_4, H_2S, NH_3, and CO_2 are quantitatively ejected to the atmosphere, i.e., there is no partitioning between the atmosphere and the condensate. Because some solution of these gases will occur in cooling tower condensate, the calculations slightly overestimate the quantities of gases emitted from plants where condensate is injected. In contrast, data on the CO_2 contents of injected fluids at The Geysers was provided, and the effect of this injection was considered when CO_2 emissions from that geothermal field were calculated. This correction was not made for emissions from flashed-steam plants.

Emissions reported in Tables 1 and 2 are weighted average values for all geothermal capacity, including binary power plants that do not emit CO_2. Data cannot be reported by power plant type because some of it is proprietary nature, but binary plants represented only 14 percent of capacity in the weighted average. Table 1 compares CO_2 emissions from geothermal power plants to those from fossil-fuel plants. CO_2 emission values for coal, petroleum and natural gas plants are calculated using data from DOE's Energy Information Administration (EIA, 2002). Table 2 shows emissions of greenhouse gases from geothermal plants per unit of geothermal electricity produced.

Recently, International Geothermal Association (IGA - Pisa, Italy) Executive Director Ruggero Bertani reported on emissions from 85 geothermal power plants currently operating in 11 countries (Bertani, 2002). His findings, with a weighted average CO_2 emission of 122 g/kWh (0.29 lbs/kWh), were similar to the rate calculated for this article. In 2001, EIA reported that coal, natural gas and oil provided 72 percent of electric power generation. Based on Table 1, these sources had a weighted average CO_2 emissions rate of 1.926 lbs/kWh. Note also that SO_x and NO_x emissions are not considered for fossil-fuel electric power production, nor are other life-cycle costs such as emissions incurred during transportation of coal to power plants.

Conclusions

Our results reveal that geothermal power production has a significant environmental advantage over burning fossil fuels for electrical power production. Electrical production from geothermal fluids results in an order of magnitude less CO_2 per kilowatt-hour of electricity produced compared to burning fossil fuels. Thus, the data clearly demonstrate that increased geothermal utilization can help the United States reduce greenhouse gas emissions, assisting National Climate Change Technology Initiative goals while helping to meet increasing power demands.

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