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Geothermal Electrical Production CO2 Emissions Study

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Production of Greenhouse Gases from Geothermal Power Plants

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ABSTRACT

Emission of "greenhouse gases" into the environment has become an increasing concern. Deregulation of the electrical market will allow consumers to select power suppliers that utilize "green power." Geothermal power is classed as "green power" and has lower emissions of carbon dioxide per kilowatt-hour of electricity than even the cleanest of fossil fuels, natural gas. However, previously published estimates of carbon dioxide emissions are relatively old and need revision. This study estimates that the average carbon dioxide emissions from geothermal and fossil fuel power plants are: geothermal 0.18 , coal 2.13, petroleum 1.56 , and natural gas 1.03 pounds of carbon dioxide per kilowatt-hour respectively.

Introduction

California was the first state in the nation to enter into deregulation of electrical production and supply. The purpose of deregulation was to move electrical production provided by the utilities into a competitive market place. As a result, consumers can now choose the generator of their electricity. Individual consumers can now reduce the impact their electrical consumption has on the environment by choosing to use renewable energy or "green power", which includes electricity generated by geothermal plants. This study was designed to update a previous estimate (Goddard and Goddard, 1990) of the quantity of carbon dioxide (CO_2), hydrogen sulfide (H_2S), methane (CH_4), and ammonia (NH_3) emitted during geothermal power generation.

The amount of carbon stored in the atmosphere has been increasing. The accumulation of atmospheric carbon dioxide (CO_2) is attributed in part to electrical generation mainly from the burning of fossil fuels, cement manufacturing, and deforestation. Elevated levels of atmospheric CO_2 are hypothesized to be causing changes in global climate.

To counteract these climatic effects, delegations from more than 150 countries met in Kyoto, Japan in December of 1997 to complete negotiations on a treaty to reduce their emissions of certain "greenhouse gases". The agreement they reached is called the Kyoto Protocol. It calls on developed nations to reduce their use of carbon emitting fossil fuels. In the U.S., CO_2 emissions account for roughly 85 percent of the emissions of the six gases named in the Kyoto Protocol. If ratified by the U.S. Senate, the U.S. will have to limit emissions of CO_2 and five other gases by 2008-2012 to 7 percent less than 1990 emissions.

This target appears to be fairly modest until the U.S. Department of Energy 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.
This is a very ambitious target and will require unprecedented action for the U.S. 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 drastically. The use of geothermal energy can be a significant contributor to reducing energy related CO_2 emissions.

Approach

The most commonly cited reference on gaseous emissions from geothermal power plants was written by Goddard and Goddard (1990). Since that earlier work the mix of dry steam, flashed steam and binary plants has changed somewhat. More importantly, injection has diminished the carbon dioxide released from geothermal power plants. Benoit and Hirtz (1994) reported that CO_2 carbon dioxide emissions from the Dixie Valley geothermal plant had decreased from 0.152 pounds of CO_2 per kilowatt-hour of electricity produced in 1988 to 0.093 in 1992.

The steam that feeds all dry-steam and flash-steam plants can contain several weight percent of non-condensable gases. The quantity of gases 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, H_2S abatement equipment). Resources that generate electricity from dry steam or through the flashing of reservoir liquids to steam contribute non-condensable gases to the atmosphere. In these plants the gases contained in the reservoir fluids pass through the turbine with the steam, but unlike the steam, they do not condense at the turbine exhaust outlet. These gases are then exhausted to the atmosphere or a primary abatement system where H_2S is removed. Binary power plants, in contrast, release no non-condensable gases because the geothermal fluids are not exposed to the atmosphere (Blaydes, 1994).

Under the Clean Air Act of 1990, there are no federal emission limits for CO_2. Consequently, formal reporting of CO_2 emissions is not required by regulatory agencies and therefore, this data is not readily available in the public domain. Regulatory agencies commonly require an emission source compliance test for other gases such as H_2S and CH_4.

Data were obtained on CO_2, CH_4 (methane), NH_3 (ammonia), and H_2S (hydrogen sulfide) from geothermal operators, utilities, and state air-quality boards. The primary sources of electrical production and CO_2 emissions data were the operators of dry steam and flash plants. The measurement of non-condensible gas in geothermal fluids is critical during initial well testing for power plant design and regulatory concerns. The non-condensable gas content is a major factor in designing condensers, non-condensable gas ejector systems and H_2S abatement systems. Non-condensable gases can be a major regulatory and permitting concern that may result in large capital and operational cost. Although there is no legal requirement for the collection of CO_2 emissions, CO_2 data is collected during required compliance tests. CO_2 data is also collected since the production of non-condensable gases is often used as a reservoir monitoring tool and an indicator of power plant energy conversion efficiency.

The data that was supplied by the 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 megawatts and concentrations of the gaseous components. The concentrations of the non-condensable gase mixtures were expressed in terms of the volume fraction of each gas in the total non-condensable gas volume, y_i. An example of the data received and the calculation of emissions per kilowatt-hour follows:

Example data:

Steam flow to plant	200,000 lbs/hr
Plant output net	10 Mwe
Sample gas/Steam ratio	10000 ppmw or 1.0%

Noncondensable gas component	Dry gas percent by volume
CO_2	97.8
H_2S	1.2
CH_4	0.5
NH_3	.05
Total	100.0

Example Calculations:
Percent by volume to percent by weight conversion:

Component	y_i volume fraction	M_i molecular weight	y_iM_i	$y_iM_i/\Sigma y_iM_i$ *weight fraction*
CO_2	0.978	44.01	43.042	0.987
H_2S	0.012	34.08	0.409	0.009
CH_4	0.005	16.04	0.08	0.0018
NH_3	0.005	17.03	0.085	0.0019
			Σy_iM_i 43.616	$\Sigma\, y_iM_i/\Sigma y_iM_i$ *1.00*

Noncondensable flow rate = Steam flow to plant ∗ Sample gas/Steam ratio
= 200,000 lbs/hr ∗ 1.0%
= 2,000 lbs/hr

Gas component flow rate = Non-condensable flow rate ∗ component weight fraction

CO_2 flow rate = 2,000 lbs/hr ∗ 0.987
= 1,974 lbs/hr

H_2S flow rate = 2,000 lbs/hr ∗ 0.009
= 18 lbs/hr

CH_4 flow rate = 2,000 lbs/hr ∗ 0.0018
= 3.6 lbs/hr

NH_3 flow rate = 2,000 lbs/hr ∗ 0.0019
= 3.8 lbs/hr

Plant steam rate = Steam flow to plant / Plant output net
= 200,000 lbs/hr / 10 Mwe
= 20,000 lbs steam / Mwe or 20 lbs steam / kw-hr

CO_2 emission rate = 1,974 lbs/hr / 10 Mwe
= 197.4 lbs/hr / Mw or 0.197 lbs / kw-hr
H_2S emission rate = 18 lbs/hr / 10 Mwe
= 0.18 lbs/hr / Mw or 0.00018 lbs / kw-hr
CH_4 emission rate = 3.6 lbs/hr / 10 Mwe
= 0.36 lbs/hr / Mw or 0.000036 lbs / kw-hr
NH_3 emission rate = 3.8 lbs/hr / 10 Mwe
= 0.38 lbs/hr / Mw or 0.000038 lbs / kw-hr

Several assumptions were made in performing the calculations. First, it was assumed that there is no partitioning of CH_4, H_2S, and NH_3 between the non-condensables ejected to the atmosphere and the condensate. Because some dissolution of these gases will occur in the cooling tower, our calculations slightly overestimate the quantities of these gases that are emitted from plants where condensate is injected. In contrast data on the CO_2 contents of the injected fluids at The Geysers was provided, and the effect of this injection has been considered when calculating CO_2 emissions from The Geysers. This correction was not made for emissions from flashed-steam plants. Secondly, our average rate includes power produced by binary plants that do not have any CO_2 emissions.

We report emissions in Tables 1 and 2 as the average value for all geothermal capacity including binary power plants. The data cannot be reported by power plant type due to the proprietary nature of some of our data. Table 1, compares the CO_2 emissions from geothermal power plants to those from fossil fuels. CO_2 values for coal, petroleum and natural gas are calculated using data taken from Electric Power Annual 1997, Volumes I and II (Energy Information Administration, 1998). Table 2 shows the emissions of "geenhouse" gases from geothermal plants per unit of geothermal electricity produced

Table 1. Comparison of Geothermal and Fossil Fuel CO_2 Emissions

	Geothermal	Coal	Petroleum	Natural Gas
Emissions (lbs. CO_2/kw-hr)	0.18	2.13	1.56	1.03

Table 2. Geothermal "Greenhouse" Gas Emissions

	CO_2	H_2S	CH_4	NH_3
Emissions (lbs./kw-hr)	0.18	1.87E-04	1.66E-03	1.39E-04

Summary and Conclusion

This investigation quantifies the concentrations of greenhouse gases emitted by geothermal power plants. The results indicate that electrical production from geothermal fluids produces an order of magnitude less CO_2 per kilowatt-hour of electricity produced than coal, petroleum and natural gas. Thus, the data clearly demonstrate how increased geothermal utilization can assist the United States in reaching the emission reductions established by the Kyoto Protocol.

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