Water Use and Geothermal Power Plants

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Life cycle, EGS, binary, flash, water consumption

ABSTRACT

With significant opportunity for growth of geothermal electricity generation through the development of enhanced geothermal systems (EGS), it is important to understand the potential environmental impacts of geothermal development. Argonne National Laboratory conducted a life cycle analysis of geothermal electric power generation systems that assessed the water requirements of these systems and potential impacts of geothermal waters on the environment.

Four power plant scenarios were evaluated: a 20-MW EGS plant, a 50-MW EGS plant, a 10-MW binary plant, and a 50-MW flash plant. Over the life cycle of a geothermal power plant for the scenarios evaluated, plant operations is where the vast majority of water consumption occurs. Although the makeup water requirements are less for a hydrothermal flash plant than for a hydrothermal binary or EGS plant, the long-term sustainability of the reservoir is less certain for hydrothermal flash due to evaporative losses of produced geofluid at operating flash plants.

The chemical composition of geofluid has important implications for plant operations and the environment. Geofluid composition was found to vary significantly both among and within geothermal fields. By comparing geofluid composition with U.S. drinking water standards, geofluids were found to present a potential risk to drinking water, if released, due to high concentrations of antimony, arsenic, lead, and mercury. The risk to drinking water can be mitigated through proper design and engineering controls. The concentration and impact of noncondensible gases (NCG) dissolved in the geofluid was also evaluated. The majority of NCG was either nitrogen or carbon dioxide, but a small number of geofluids contain potentially recoverable concentrations of hydrogen or methane.

This is part of a larger effort to compare the life cycle impacts of large-scale geothermal electricity generation with other power generation technologies.

Introduction

The Energy Information Administration (EIA) of the U.S. Department of Energy (DOE) projects that renewable electricity, which now represents around 8.5% of U.S. electricity generation, will increase to about 17% by 2035 (USEIA, 2010). Geothermal electricity generation is projected to increase 60% during the same time frame. To understand the potential environmental impacts of future geothermal industry growth, Argonne National Laboratory carried out a life cycle analysis (LCA) that quantified energy, water, and environmental impacts of geothermal power plants by examining proximity to infrastructure, resource availability, and tradeoffs associated with well depth and resource temperature (Sullivan et al., 2010; Clark et al., 2011). The scope of the work presented here is limited to the quantification of onsite water requirements and the potential environmental impacts from geothermal waters. While materials for the construction of geothermal power plants have upstream water burdens embedded in industrial processes and energy consumption, their water impacts are not necessarily allocated to the watershed or aquifers associated with a power plant and are not included in this analysis.

Methods

The LCA focused on four power plant scenarios: a 20-MW EGS plant, a 50-MW EGS plant, a 10-MW binary plant, and a 50-MW flash plant. The EGS and binary scenarios assume air-cooled power plants, whereas the flash plant scenario assumes evaporative cooling. In considering water use at power plants, two water quantities are commonly listed: water withdrawn and water consumed. The former is defined as water taken from ground or surface water sources mostly used for heat exchangers and cooling water makeup, whereas the latter is water either consumed in the combustion process (e.g., in coal and biomass gasification plants — not covered here) or evaporated and hence no longer available for use in the area where it was withdrawn. In this analysis, water consumption also includes water withdrawals related to construction stage activities (e.g., in drilling muds and cement) for the four scenarios. The objective of this work is to account for the consumed water — withdrawn water that does not get returned to its area of extraction in liquid form. This analysis did not account for geofluid from the reservoir that is lost but not replaced. Losses to the atmosphere via evaporation at hydrothermal flash plants or to the formation due to reservoir characteristics may impact the long term sustainability of such projects. The scenarios were run in DOE's Geothermal Electricity Technology Evaluation Model (GETEM) repetitively to create a range of possible outcomes according to various physical conditions including temperature and flowrate.

To assess the water quality of typical geofluids, a search was performed to obtain chemical composition data. Five datasets were obtained and merged into a single database to facilitate further analysis (Garside, 1994; GBCCE, 2010; Mariner, 2010; Moore, 2010; USGS, 2006; USGS, 1983).

The original datasets were taken as-is with minimal quality control. Only the NatCarb brine data were trimmed because the original dataset contained over 125,000 samples, many of which were not near geothermal sources. Only samples with temperatures above 90°C from this dataset were included in the merged database. The complete merged database is referred to as the Argonne Geothermal Geochemical Database (AGGD) to differentiate it from its component datasets. The complete database can be downloaded at www.anl.gov/renewables/research/geothermal.html. Data in the AGGD were organized by temperature on the basis of USGS designations of low-temperature (<90°C), moderate-temperature (90°C–150°C), and high-temperature (>150°C) geothermal sources (Duffield and Sass, 2003). Because many records did not include a temperature value, approximately 2,300 moderate-temperature data points and 800 high-temperature data points were used for most of the analyses. See Clark et al. (2011) for a more thorough discussion of methods.

Results and Discussion

For the scenarios evaluated, power plant operations was the life cycle stage where the vast majority of water consumption occurs as shown in Table 1. For the EGS scenarios, plant operations consume between 0.29 and 0.72 gal/kWh. The binary plant experiences similar operational consumption, at 0.27 gal/kWh. The operation water losses for the binary and EGS scenarios were based on available data for operating air-cooled systems, although the data are likely high due to evaporative cooling operations during the daytime during summer months. While operational water losses for air-cooled systems may be overestimated in the EGS scenarios, potential subsurface water losses from reservoir stimulation are not accounted for due to insufficient empirical data to support a reservoir water loss estimate.

As geofluid is used for cooling and is not replaced in the flash plant scenario, far less water, just 0.01 gal/kWh, is consumed during operations. While the makeup water requirements are less for a hydrothermal flash plant, the long-term sustainability of the reservoir is less certain due to estimated evaporative losses of 14.5–33% of produced geofluid at operating flash plants. For the hydrothermal flash scenario, the average loss of geofluid due to evaporation, drift, and blowdown is 2.7 gal/kWh.

Table 1. Average Water Consumption Estimates for Geothermal Power Generation by Life Cycle Stage over Plant Lifetime in Gallons per Kilowatt-Hour of Lifetime Energy Output.

Scenario	Construction and EGS Stimulation (gal/kWh)	Operations (gal/kWh)	Total (gal/kWh)
20-MW EGS	0.01	0.29–0.72	0.30–0.73
50-MW EGS	0.01	0.29–0.72	0.30–0.73
10-MW binary	0.001	0.27	0.27
50-MW flash	0.001	0.01	0.01

This LCA found the water consumption for EGS power plants to be 0.30–0.72 gal/kWh over the lifetime energy output. These findings are similar to those reported in Frick et al. (2010), who provided component estimates of consumption that aggregate to 0.36 gal/kWh over the lifetime energy output. However, Frick et al. (2010) identified the construction stage, particularly well stimulation or "reservoir enhancement," as the stage where most of the water is consumed. While stimulation dominated the construction stage volume requirements in this LCA, over the lifetime energy output the volume for the entire construction stage is 0.01 gal/kWh for EGS. It is unclear why there is such a large difference; however if "reservoir enhancement" includes additional makeup water over time due to water loss, Frick et al.'s operation water loss results are similar to this LCA's.

For the water quality impact analysis, an extensive dataset containing more than 53,000 geothermal geochemical data points was compiled and analyzed for general trends and statistics for typical geofluids. Geofluid composition varied significantly both among and within geothermal fields. The pH values appear to be roughly normally distributed around a median of 7.3, with most values falling between 5 and 10. The range of the data varies from as low as 0.9 to as high as 11.8. Total dissolved solid (TDS) values are less neatly distributed, with 80% of samples with a value less than 5,000 mg/L and 10% of samples with a value greater than 200,000 mg/L (all of the latter samples were from wells in California). The dissolved solids in most geofluids are predominantly sodium chloride, followed by bicarbonate, sulfate, silica, calcium, and potassium. By comparing geofluid composition with U.S. drinking water standards, geofluids were found to present a potential risk to drinking water, if released, due to high concentrations of antimony, arsenic, lead, and mercury (USEPA, 2010). The risk to drinking water can be mitigated through proper design and engineering controls.

The concentration and impact of noncondensible gases (NCG) dissolved in the geofluid was also evaluated. Commonly encountered NCGs include nitrogen, carbon dioxide, hydrogen sulfide, methane, argon, and oxygen. These gases are released when steam is flashed and collect in the condenser of flash and steam systems. They must be removed to maintain efficient operation of the system. They are usually released to the atmosphere, except for hydrogen sulfide, which must be scrubbed prior to release. The majority of NCG was either nitrogen or carbon dioxide as shown in Figure 1, but there are cases where the two gases are mixed more evenly. The concentration distributions are almost identical for both gases, with most samples clustered over 90% or under 5%. The combined concentration of these two gases is over 65% in 90% of samples and over 90% in 76% of samples. Concentrations of hydrogen sulfide, methane, oxygen, hydrogen, and argon are typically under 1% each but can reach as high as 10% in some cases. There is also a small subset of cases where either hydrogen or methane dominates the composition with concentrations over 60%.

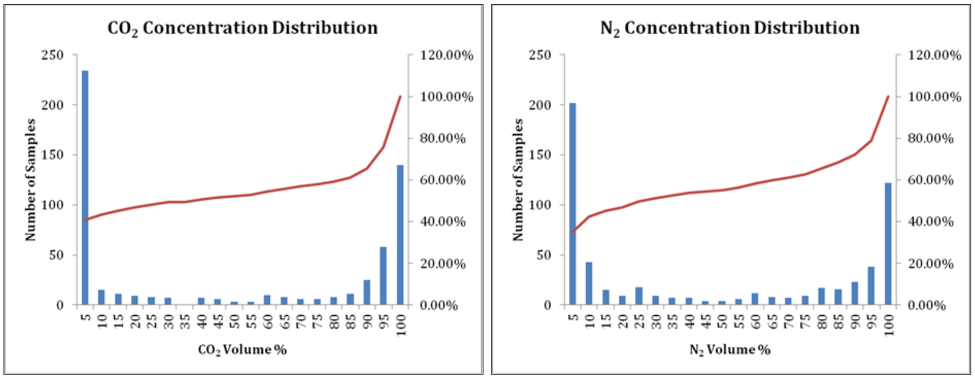

Figure 1. Histogram of Concentrations of (a) Carbon Dioxide and (b) Nitrogen in NCG Stream.

Variability in NCG composition is an important design consideration, at least for flash and steam systems. Increasing concerns over GHG emissions may require limiting emissions in the future. Compressing and reinjecting the NCGs into the reservoir with the spent geofluid is an option for limiting emissions from resources with higher CO_2 concentrations. This process, however, would result in additional parasitic power consumption (Tester et al., 2006). Targeting reservoirs with lower carbon dioxide concentrations is another option for limiting emissions. In addition to emissions concerns there are also locations with elevated hydrogen or methane concentrations. These gases could be separated and collected for use on site or sold into the market as an additional energy and revenue stream.

Summary

For all geothermal systems evaluated, the operational makeup water requirement was found to be the largest consumer of water. While operational water losses for air-cooled systems may be overestimated in the EGS scenarios, potential subsurface water losses from reservoir stimulation are not accounted for. Insufficient empirical data exists to support a reservoir water loss estimate; further research may support a reasonable estimate in the future.

Comparison of the geofluid composition with U.S. drinking water standards concluded that geothermal waters pose a large potential risk to water quality, if released into the environment, due to high concentrations of toxics including antimony, arsenic, lead, and mercury. However, the risk of release can be reduced through proper design and engineering controls.

The results of this LCA lead to the following recommendations to reduce the life cycle water intensity or improve operations of geothermal power plants.

1. **Reuse water.** Reusing water during drilling and hydraulic stimulation can reduce the estimated volume of water for these activities. When multiple wells are drilled or stimulated on a site, temporarily storing fluids between activities could reduce overall water volumes.
2. **Evaluate operational water use.** There is a lack of available data to identify where water consumption is occurring during operations, especially for air-cooled systems. Further evaluation could identify processes that are consuming water and possibly present opportunities for improving operational water use efficiency.
3. **Consider nonfreshwater makeup sources.** Shifting water consumption to nonfreshwater sources when feasible may be an effective solution to water consumption concerns. Alternative sources include oil and gas production water, carbon capture and storage production water, and saline groundwater.
4. **Encourage use of binary systems.** Binary systems were found to mitigate or minimize some of the major environmental and operational impacts resulting from the geofluid composition. They eliminate the venting of NCG, reducing the carbon footprint and the need for hydrogen sulfide controls. Binary systems also enhance the sustainability of the reservoir by avoiding geofluid evaporative cooling losses.

Through these efforts, efficiency improvements can be made across the geothermal power plant life cycle to further reduce the impacts of geothermal power on freshwater resources.

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