PROCEEDINGS, Thirty-Fourth Workshop on Geothermal Reservoir Engineering
Stanford University, Stanford, California, February 9-11, 2009
SGP-TR-187

PRE-PRODUCTION ACTIVITY IMPACTS OF ENHANCED GEOTHERMAL SYSTEMS

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ABSTRACT

Research into the sustainability of geothermal energy previously focused on the management and use of the resource (Rybach and Mongillo, 2006) and the environmental impacts during geothermal energy production (Bloomfield et al., 2003; Reed and Renner, 1995). Within these constraints, studies have shown that there will be less impact on air emissions (including greenhouse gases), water consumption, and land use from geothermal electricity generation than from traditional fossil-fuel–based electricity generators. However, the environmental impacts from the construction of geothermal energy production facilities are less well understood, especially for enhanced geothermal systems (EGSs).

With the U.S. Department of Energy's commitment to support research and development of EGS and the potential total production capacity for EGS in the United States expected to exceed 100,000 MW, the life-cycle impacts of the technology must be explored (Tester et al., 2006). This paper discusses potential impacts and factors associated with EGS transportation, construction, drilling, and production. Including the impacts from pre-production activities allows us to more accurately assess and compare EGSs to fossil fuel-based electricity generators.

INTRODUCTION

It is generally recognized that electricity production from geothermal power plants releases fewer emissions than do traditional fossil-based sources. This fact, combined with the size and availability of the geothermal resource within the U.S., has led to increased interest in this sustainable technology. On December 18, 2008, the Department of the Interior's Bureau of Land Management (BLM) eased development of geothermal energy production by making more than 190 million acres of federal land available for leasing and development (U.S. DOI, 2008).

The decision by BLM was made after completion of a programmatic environmental impact statement (EIS). The EIS complies with the National Environmental Policy Act (NEPA) of 1969, which requires federal agencies to incorporate the environmental consequences of proposed actions and reasonable alternatives into the decision-making process. While the impacts discussed in the programmatic EIS were not found to warrant a change to the proposed action (leasing), and while other assessments have similarly found in favor of geothermal energy production, the environmental impacts considered do not include costs across the entire life cycle of geothermal energy production. The consideration of life-cycle impacts is necessary to understand the full environmental impact of projects, especially when the potential for large-scale development exists. For geothermal energy production to serve as a significant alternative to fossil-based electricity generation for the U.S., advanced technologies for enhanced geothermal systems (EGSs) will likely be considered. This paper discusses potential impacts associated with EGS transportation, construction, drilling, and production and summarizes current policy issues related to geothermal energy production.

EXISTING ASSESSMENTS OF GEOTHERMAL TECHNOLOGY

Utilizing geothermal resources for electricity generation has been possible since 1904 (Lund, 2004). The technology has grown considerably since then, and with the increasing interest in scaling up production, a number of studies have considered environmental impacts of the technology. What follows is a brief summary of the impacts of conventional projects and of EGSs.

Conventional Geothermal Systems

EISs of geothermal projects have noted environmental impacts that include the following: aquifer contamination from additives, gaseous emissions, land disturbance, noise pollution, water consumption and use, and visible effects on the surroundings (Lee, 2004).

Several of these are not considered to significantly impact surrounding areas. While noise pollution will occur during drilling, construction, and operation (primarily from cooling towers), the generated noise is less than noise from airplane traffic (Lee, 2004; Kubo, 2003). Although the views in remote areas may be affected from geothermal production activities, through careful design considerations, the impacts from construction and operation activities can be mitigated. In addition, the footprint of surface activities, when compared to that associated with other electric generators, is relatively small (U.S. DOI and USDA, 2008).

There may be risk to aquifers from equipment and well maintenance. During drilling and operations, additives may be used to reduce solid deposition on equipment and casings. Care in site selection can mitigate much of this risk. Alternatives to additives may include solid collection and removal, and proper management of the generated waste can minimize surface impacts.

Concerns over gaseous emissions from geothermal activities primarily focus on hydrogen sulfide (H_2S). Emissions of H_2S depend on the resource but must meet emission standards to control odor and reduce health risk. In addition to H_2S, carbon dioxide (CO_2) is also emitted from geothermal power plants. Other species include methane, hydrogen, sulfur dioxide (SO_2), and ammonia, although they are often present only in low concentrations. Generally, emissions are low especially when compared to those associated with traditional nonrenewable fossil energy sources for electricity generation, as shown in Table 1. Emissions from geothermal electricity generation depend on the technology used, with closed-loop binary systems mitigating emissions as the geothermal fluid remains enclosed in the system to transfer heat to a secondary fluid that is used to generate electricity.

For conventional geothermal projects, land subsidence is common yet difficult to predict. Monitoring from the initial development assists in minimizing subsidence. Excessive production of fluid from a resource can cause subsidence and affect surface manifestations (e.g. fumaroles, geysers, mud pools) (Lee, 2004). Fluid injections can maintain pressure and mitigate these effects (Sorey, 2000).

Energy Source	**CO_2 (kg/MWh)**	**Source**
Geothermal		
Average	25.7	EIA, 2008
Weighted average	90	Bloomfield et al., 2003
Hydrothermal – flash steam	27.2	Kagel et al., 2007
Hydrothermal – dry steam field	40.3	Kagel et al., 2007
Hydrothermal – closed-loop binary	0	Kagel et al., 2007
Coal-fired	994	Kagel et al., 2007
	950	Bloomfield et al., 2003
Oil-fired	758	Kagel et al., 2007
	893	Bloomfield et al., 2003
Gas-fired	550	Kagel et al., 2007
	599	Bloomfield et al., 2003

Table 1: CO_2 emissions for various types of electricity-generating power plants.

Conventional geothermal sources typically use available water within the geothermal resource. Depending on the technology employed for electricity generation, production can lower the water table affecting surrounding areas (Tester et al., 2006; Lee, 2004). In addition to being used for energy generation, water is typically used for cooling the working fluid in the plant. Cooling towers are used when makeup water from nearby surface waters or other water supplies are available. Air cooling is an effective alternative when water supplies are limited.

Enhanced Geothermal

EGSs can expand the electricity-generating capacity of geothermal resources. When water is injected into the subsurface, the formation can be fractured, allowing water to be circulated through the resource. These systems can be implemented in formations that are dryer and deeper than conventional geothermal resources (U.S. DOE, 2008a). Because of increased depths and temperatures and decreased water availability, environmental impacts from EGSs can be different from those from conventional geothermal power plants.

In 2006, a study by the Massachusetts Institute of Technology assessed the feasibility of developing EGSs to meet a substantial portion of the U.S. energy demand. The primary focus of the assessment was the availability and accessibility of the geologic resource and the economic feasibility of the task (Tester et al., 2006). While environmental impacts were described, the study focused on the technological and economic feasibility of EGSs (U.S. DOE, 2008b).

Since significant geothermal resources appropriate for EGSs are often in water-stressed regions, air cooling may be used more frequently for EGS than for traditional projects. This may increase noise levels, since air-cooled condensers have many cells, each with a fan (Tester et al., 2006).

Current geothermal capacity under conventional means is 2,930 MW (U.S. DOE, 2008b). Since the electricity generation capacity of EGSs could reach 100,000 MW by 2050 (Tester et al., 2006), EGSs are expected to have greater visual impacts than conventional geothermal power plants.

Generally, it is expected that EGS installations will have lower amounts of dissolved gases (Tester et al., 2006). The use of binary systems can avoid the burden of scrubbing or chemical treatment for noncondensable gas removal by recovering the heat through a heat exchanger and reinjecting the fluid without releasing any gas.

Unlike conventional geothermal systems, enhanced geothermal systems are not expected to experience subsidence issues. This is due to the field being pressurized to keep the fractures open and the amount of fluid maintained in the reservoir during the operation of the plant (Tester et al., 2006). However, the constant pressure to the system has the potential to induce seismicity. Care needs to be taken during the stimulation process to mitigate the risk. Site selection also plays a key role in minimizing the risk of unintended seismic consequences.

Water is required for both traditional geothermal and enhanced geothermal systems. For traditional projects, the water available at the resource is typically used. However, for EGSs, where the availability of water at the resource may be limited due to the low hydraulic conductivity of the formation, additional water will be required. Water will be needed for (1) hydraulic fracturing of the formation to stimulate the resource and (2) during the operation and use phase. Although water that is produced from the formation for use in the power plant is reinjected, some water is lost to the formation. To maintain pressure and operation, water that is lost must be made up from alternative water sources.

While there is the potential for contamination of aquifers above the resource for both conventional geothermal and enhanced geothermal systems if well casings leak, dissolved solids increase significantly, with the temperature increasing the magnitude of contamination should a leak occur within an EGS. Risk can be mitigated through redundancy in strings within the casings. Surface contamination is mitigated within an EGS through reinjection of produced fluid, although solids collection or chemical treatment may be required to address precipitation of dissolved solids after heat transfer.

Limitations of Existing Assessments

While emissions during the use phase of a geothermal plant has been investigated (Bloomfield et al., 2003; Kagel et al., 2007), life-cycle impacts have not been explored. These include the energy and material costs associated with construction and the transportation of water to and from the plant and impacts associated with activation of the resource, as summarized in Figure 1. Traditional life-cycle assessment identifies, quantifies, and assesses the environmental impacts of a product, process, or activity (e.g., electricity production) from resource extraction to end-of-life management, or “cradle to grave” (Elcock, 2007). Currently, the quantification of these impacts is difficult due to the limited number of geothermal projects, especially for EGSs. However, lessons may be learned from investigations of the life cycle of oil and gas activities.

LESSONS FROM OIL AND GAS ACTIVITIES

Despite the limited availability of life-cycle data for geothermal power generation, information on the significant impacts within the life cycle can be obtained through an understanding of the life cycles of oil and gas activities. In this section, energy, material, and water consumption associated with drilling and production activities from the oil and gas industry are explored and applied to geothermal electricity production.

Energy and Material Consumption

According to a life-cycle assessment of a natural gas combined-cycle (NGCC) power generation system, the upstream processes for extracting and transporting natural gas consumed the most energy, with 98% of energy consumption within the life cycle due to the natural gas production and transport phase (Spath and Mann, 2000). As a result, 0.4 MJ of electricity are produced per 1 MJ of fossil energy consumed (Spath and Mann, 2000).

EGSs rely on extraction and transportation of a subsurface fluid, which suggests that the life cycle of EGSs may also be dominated by the production and transport phase. However, since geothermal power plants are built on the site of the geothermal resource, the transportation burden should be significantly less than the natural gas transportation burden. In the assessment by Spath and Mann, 2,486 mi (4,000 km) were attributable to pipeline transport. According to a programmatic EIS for geothermal energy production, conventional geothermal plants have between 1.5 and 7 mi (2.4 and 11.3 km) of 8-in.- (20.3-cm)-diameter pipes (U.S. DOI and USDA, 2008). However, with EGSs in water-stressed regions, transportation pipelines may be necessary to bring in water from distant surface waters or municipal distribution systems.

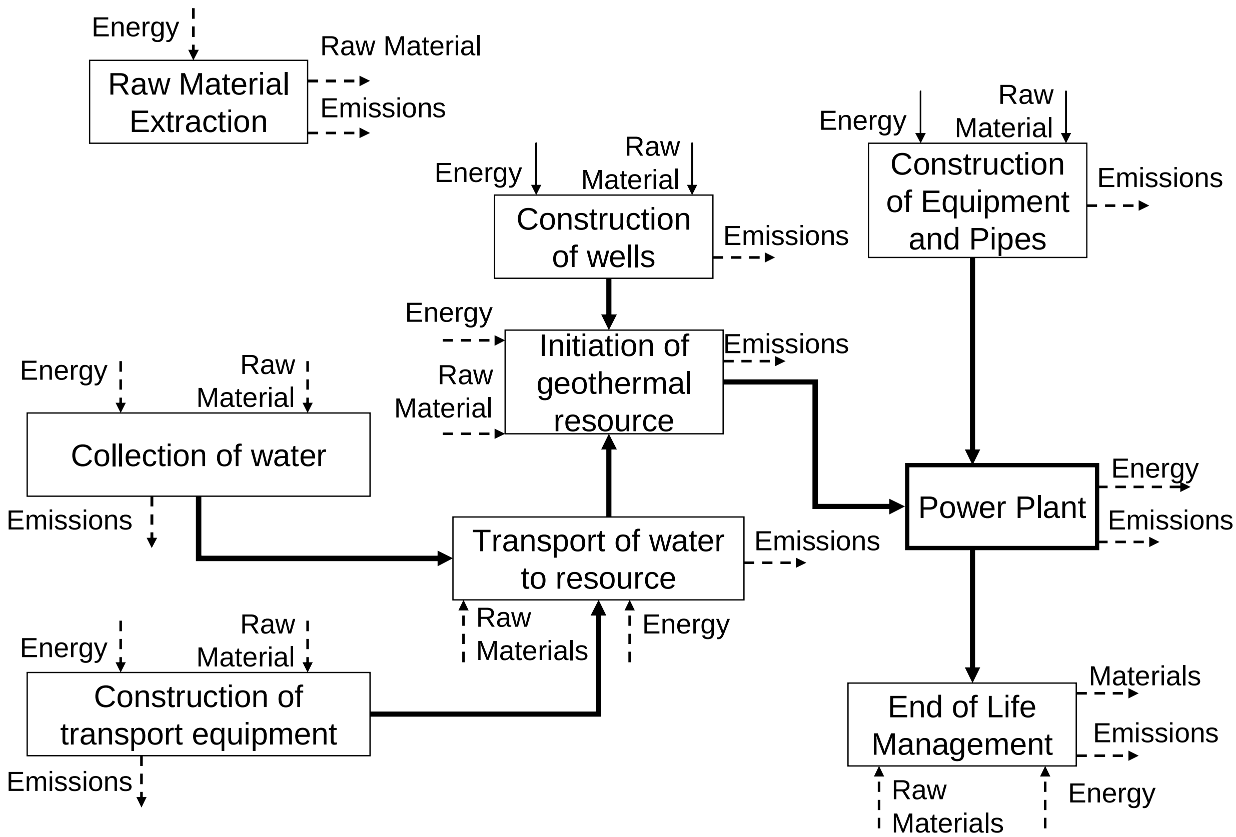

Figure 1: Life cycle flow diagram for an enhanced geothermal system (EGS) power generation plant. The inputs (e.g. energy and raw material) and outputs (e.g. energy and emissions) are included for each stage of the life cycle.

In addition to energy consumed during transport, embedded energy is present in the materials used to transport fluids to the power plant. In the NGCC power plant example, the majority of the material in the life cycle is bound in the pipeline. The pipeline with an average diameter of 30 in. (76.2 cm) is responsible for 94,336 Mg of steel attributed to the life cycle of the NGCC plant (Spath and Mann, 2000). This represents only 19.3% of the total pipeline material, since a pipeline typically has many users. As the steel industry consumes about 1470 MJ per metric ton (Mg) of steel shipped (AISI, 2005), the NGCC power plant's portion of the pipeline contains 1.39E+08 MJ of embedded energy. According to dimensions provided in the programmatic EIS, a geothermal pipeline may have up to 368 Mg of steel with 5.4E+06 MJ of embedded energy. Since energy for steel production is provided through fossil fuel sources, the energy used to manufacture the pipeline contributed to a considerable amount of emissions that are not accounted for in the CO_2 estimates from geothermal power plant production listed in Table 1. If a conservative emission factor of 434 kg CO_2/MWh (0.09 kg CO_2/MJ) from coal combustion (U.S. LCI Database, 1998) is assumed instead of assuming the coal combustion emission factors in Table 1, 469 Mg of CO_2 would be unaccounted for.

well and pipe infrastructure. Augustine et al. (2006) performed a study comparing the costs of geothermal wells and oil and gas wells. The authors found that casing and cementing costs revealed a step change in costs at depths greater than 6,000 m. For wells beyond this depth, the number of casing strings is increased from three to four. EGSs can be assumed to have a greater CO_2 burden than traditional geothermal systems, as additional steel casing strings are required for EGS. Metal casings are typically held in place by cement (another energy-intensive material), and CO_2 emissions can also be attributed to manufacturing of the cement. For cement manufacturing, energy consumption is 6,200 MJ/Mg of cement, and the CO_2 intensity (including fuel consumption and raw material calcinations) is 935 kg CO_2/Mg of cement (Worrell and Galitsky, 2008).

Water Consumption for Resource Activation

One of the challenges facing EGS power plants is finding water for hydraulic fracturing of the geothermal resource and for production purposes in regions with limited or no water. The amount of water required for both activities depends on a variety of factors, including the size and type of the formation, the hydraulic conductivity of the formation, and the amount of water present in the formation. While the term *massive frac job* refers to a large fracturing job that could use 750,000 gal (3,000,000 L) of fracturing fluid and 2,000,000 lb (900 Mg) of sand (Hyne, 1995), a typical fracturing job is more difficult to estimate.

In 2004, the U.S. Environmental Protection Agency (U.S. EPA) conducted a study evaluating the risk to underground drinking water sources from hydraulic fracturing in coal-bed methane (CBM) reserves. The study evaluated activities in several formations. Fracture stimulation injections typically ranged from 55,000 to 300,000 gal (208,000 to 1,100,000 L) of water per treatment and 200,000 to 1,300,000 lb (91 to 590 Mg) of sand (US EPA, 2004). While information is more readily available on CBM fracturing projects, these generally require less water than would be required for the deep and tight formations that EGSs may use. The water consumption for EGS projects may be more similar to that for unconventional shale gas hydraulic fracturing jobs For multistage, horizontal fracturing jobs in the Fayetteville Shale and Marcellus Shale, 3,000,000 to 5,000,000 gal (11,400,000 to 18,900,000 L) of water are needed per well.

Sources for water used for hydraulic fracturing include surface water, municipal water, groundwater, produced water from oil and gas activities, or other recycled water. For EGS activities, water would most likely be transported from off site either via pipeline or truck. Delivery methods would further increase the energy and emissions burden of EGS.

Current Policy and Outlook

For any geothermal project, there are numerous laws and regulations that must be met that include environmental regulations, occupational health and safety requirements, and cultural resources and sensitivity requirements (DiPippo, 2008). Since EGSs have significant water demands, this section focuses on the relevant policies under the Clean Water Act.

Geothermal electricity production is primarily regulated through the Underground Injection Control (UIC) Program under the Clean Water Act. The UIC Program regulates injection wells that are used to dispose of spent geothermal fluids following power generation. These wells fall under Class V injection wells (40 CFR 144.24). Under Class V, operators may not endanger underground sources of drinking water (USDWs) (40 CFR 144.12), and they must submit basic inventory information (40 CFR 144.26).

For EGSs, hydraulic fracturing is needed to stimulate the resource. The UIC Program also applies to hydraulic fracturing for the following activities:

1. Well injection of fluids into a formation to enhance oil and gas production (Class II wells);
2. Hydraulic fracturing used in connection with Class II and Class V injection wells to stimulate a formation; and
3. Hydraulic fracturing activities to produce methane from coal beds in the state of Alabama.

Fracturing for geothermal energy production purposes would be covered under the second activity. Most states have received delegation of portions or all of the UIC Program; state permits may be more restrictive than U.S. EPA permits.

The Safe Drinking Water Act (SDWA) covers protection of groundwater aquifers that may be accessed to provide drinking water. However, hydraulic fracturing activities are excluded from the SDWA. This exclusion was provided in the Energy Policy Act of 2005, Subtitle C, Section 322, which modified SDWA Section 1421(d), Paragraph (1) to define *underground injection* as the following:

> "(A) means the subsurface emplacement of fluids by well injection; and
> (B) excludes –
> (i) the underground injection of natural gas for purposes of storage; and
> (ii) the underground injection of fluids or propping agents (other than diesel fluids) pursuant to hydraulic fracturing operations related to oil, gas, or geothermal production activities."

The rationale for this exclusion was based on the 2004 study by the U.S. EPA, which investigated hydraulic fracturing at CBM reservoirs. Since CBM reservoirs are shallow, it was assumed that if there was little risk to USDWs from fracturing CBM reservoirs, then deeper fracturing activities associated with oil, gas, and geothermal activities should pose little risk to USDWs.

Concerns exist over the validity of the above assumption. The Obama transition team requested and received a list of existing exemptions from environmental regulations for the oil and gas industry (InsideEPA, 2009). A previous bill (H.R. 7321) introduced by Rep. Diana DeGette (D-CA) in September that is expected to be reintroduced in the 111th Congress would remove the SDWA exemption (InsideEPA, 2009). In addition to concerns of hydraulic fracturing for oil and gas activities, the U.S. EPA was critical of the draft programmatic EIS for geothermal leases on federal lands, raising concerns on air quality and sole source aquifer water quality (InsideEPA, 2008). Further understanding of the impacts and risks of hydraulic fracturing in EGSs could better inform the ongoing policy debate.

In addition to water quality concerns, understanding the embedded energy within EGS technology may become more important, depending on national greenhouse gas policies. With the House Energy and Commerce Chairman Henry Waxman preparing to move climate and energy legislation out of committee before the end of May 2009, air emissions from geothermal electricity production may face greater scrutiny (Samuelsohn, 2009).

While geothermal power plants may come under greater environmental regulation, the benefits of geothermal energy should not be ignored. As our energy supply shifts toward more renewable sources, the emissions burden of materials required for EGSs will decrease, improving the overall life-cycle burden of the technology.

ACKNOWLEDGMENT

Work supported by the U.S. Department of Energy, under contract DE-AC02-06CH11357.

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