Geothermal Water Consumption and Life Cycle Water Analysis

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Keywords

Life cycle, water, water consumption, EGS, flash, hydrothermal, binary

ABSTRACT

This paper examines life cycle water consumption for various geothermal technologies to better understand factors that affect water consumption across the life cycle (e.g., power plant cooling, belowground fluid losses) and to assess the potential water challenges that future geothermal power generation projects may face. This analysis extends previous life cycle analyses to evaluate freshwater requirements of geothermal power-generating systems by including new technology scenarios, including flash enhanced geothermal systems (EGS), to further understand how technology improvements could impact life cycle water consumption. Results show that geothermal water consumption greatly relies on technology selection. Additionally, reservoir loss is particularly important for consumption of EGS, as this parameter dominates the analysis for binary systems. Finally, resource temperature and water consumption also appear to be positively correlated, with consumption generally rising as resource temperature increases.

Introduction

According to the Energy Information Administration (EIA) of the U.S. Department of Energy (DOE), geothermal energy generation in the United States is projected to more than triple by 2040 with the addition of more than 5 GW of generation capacity through the continued development of enhanced geothermal systems (EGS) and low-temperature resources (EIA 2013). Although studies have shown that geothermal electricity generation has a smaller impact on air emissions, water consumption, and land use than traditional fossil fuel–based electricity generation, the long-term sustainability of geothermal power plants can be affected by insufficient replacement of aboveground or belowground operational fluid losses resulting from normal operations.

Over the past several years, Argonne has examined geothermal water consumption across a range of technologies. This paper examines life cycle water consumption for various geothermal technologies to better understand factors (e.g., power plant cooling, belowground fluid losses) that affect water consumption across the life cycle. The methods used in this report closely follow those employed in previous analyses, notably those of Sullivan et al. (2010), Clark et al. (2011, 2012, 2013), and Schroeder et al. (2014). This paper seeks to extend Argonne's previous work by including flash EGS and examining the effect of future technology improvements on freshwater consumption.

Methods

For the purpose of conducting a life cycle analysis, a number of hypothetical geothermal power plant scenarios were used. A standardized set of scenarios was developed by DOE's Geothermal Technologies Office (GTO) with input from national laboratory and industry experts (see Tables 1 and 2) for evaluation of the levelized cost of electricity (LCOE) and the associated environmental impacts of geothermal technologies. These scenarios were provided by the GTO for consistency between this and any other analyses that might rely on these scenarios, such as that of Sullivan et al. (2013). The scenarios were run repetitively in DOE's Geothermal Electricity Technology Evaluation Model (GETEM) to create a range of possible outcomes by varying select parameters (DOE 2011a). Key parameter values from the scenario definitions and select GETEM outputs were then used to help calculate the life cycle water consumption for each scenario. These values included, but were not limited to, the number of production and injection wells, the well flow rates, the water consumption for flash system cooling, and the plant lifetime.

GTO developed 10 scenarios, half of which focus on hydrothermal plants and half of which focus on EGS power plants. Each scenario was run in GETEM with a "Reference" set of parameters and an "Improved" set of parameters to create a total of 20 scenarios. For the EGS scenarios, the Improved scenarios were developed to reduce the LCOE for that configuration by a combination of increased well flow rate, capacity, extended plant lifetime, reduced thermal drawdown rate, fewer exploration well sites, advances in drilling technology, and finally, alternative financing (Sullivan et al. 2013). Additionally, for EGS, reservoir loss rates decrease from 5% in the Reference scenarios to 1% in the Improved scenarios. For the binary hydrothermal scenarios, reductions in LCOE were primarily brought about by increasing the number of production wells at constant well flow rates and hence, plant capacity (Sullivan et al. 2013). In addition, the difference in the scenarios also involved forecasting the level of technology available in the future. For example, the EGS Reference scenarios were run assuming current technology available in 2012. However, EGS Improved scenarios were run assuming technological breakthroughs available in 2030, which would help lower the LCOE. For example, increased engineering efficiency available in 2030 would, it is assumed, allow operators to extract heat more efficiently, both technically and economically. Better exploration technology would mean fewer exploration well sites. Better drilling technology would lead to reservoirs that are more efficiently connected, leading to less water loss. These assumptions are also true of the Improved hydrothermal scenarios, with the exception that the forecast was extended out to 2020, not 2030.

Previously, it was assumed that the EGS would rely upon binary technology for electric power generation. Several flash EGS scenarios were developed and evaluated in this analysis. Also, subsurface water loss was investigated across the range of EGS scenarios, providing more insight into the influence of reservoir performance on the importance of this key life cycle stage. Loss rates of either 1% or 5% were analyzed as specified in the scenario definitions. The 5% loss rate is consistent with data from the limited number of EGS test projects to date, while the 1% value has been achieved at one site and may be achievable at additional sites in the future with improved understanding of these systems and the causes of belowground water loss.

Table 1. GETEM EGS Scenarios[a].

Parameter	Scenario 1		Scenario 2		Scenario 3		Scenario 4		Scenario 5	
	Reference	Improved	Reference	Improved	Reference	Improved	Reference	Improved	Reference	Improved
Power sales (MW)	10	25	15	35	20	40	25	50	30	50
Generator type	Binary	Binary	Binary	Binary	Binary	Binary	Flash	Flash	Flash	Flash
Cooling type	Air	Air	Air	Air	Air	Air	Wet	Wet	Wet	Wet
Temperature (°C)	100	100	150	150	175	175	250	250	325	325
Injection to production ratio	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Well depth (km)	2	2	2.5	2.5	3	3	3.5	3.5	4	4
Production flow rate (kg/s)	40	100	40	100	40	100	40	80	40	80
Subsurface water loss (% produced flow)	5	1	5	1	5	1	5	1	5	1
Plant lifetime (yr)	20	30	20	30	20	30	20	30	20	30
Well field stimulation	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Flash steam cycle water loss (%)	*0*	*0*	*0*	*0*	*0*	*0*	*23.2*	*23.6*	*29.8*	*30.3*
Number of production wells	*22*	*23*	*8*	*9*	*8*	*8*	*6*	*6*	*4*	*3*
Number of injection wells	*11*	*11*	*4*	*5*	*4*	*4*	*3*	*3*	*2*	*2*

[a] *Italicized information represents data that were output from GETEM.*

Table 2. GETEM Hydrothermal Scenarios[a].

Parameter	Scenario 6		Scenario 7		Scenario 8		Scenario 9		Scenario 10	
	Reference	Improved	Reference	Improved	Reference	Improved	Reference	Improved	Reference	Improved
Power sales (MW)	15	20	30	50	30	50	40	50	15	25
Generator type	Binary	Binary	Flash	Flash	Binary	Binary	Flash	Flash	Binary	Binary
Cooling type	Air	Air	Wet	Wet	Air	Air	Wet	Wet	Air	Air
Temperature (°C)	140	140	175	175	175	175	225	225	140	140
Injection to production ratio	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75
Well depth (km)	1.5	1.5	1.5	1.5	1.5	1.5	2.5	2.5	2.5	2.5
Production flow rate (kg/s)	100	100	80	80	100	100	80	80	100	100
Subsurface water loss (% produced flow)	0	0	0	0	0	0	0	0	0	0
Plant lifetime (yr)	30	30	30	30	30	30	30	30	30	30
Well field stimulation	No	No	No	No	No	No	No	No	No	No
Flash steam cycle water loss (%)	*0*	*0*	*15.5*	*15.5*	*0*	*0*	*22.5*	*22.3*	*0*	*0*
Number of production wells	*5*	*9*	*9*	*15*	*6*	*11*	*6*	*7*	*4*	*8*
Number of injection wells	*4*	*7*	*7*	*11*	*5*	*8*	*5*	*6*	*3*	*6*

[a] *Italicized information represents data that were output from GETEM.*

The different life cycle stages represented in this analysis are defined below. The first stage, *Drilling and Construction*, includes all water consumed during well drilling, pipeline construction, and power plant construction. As in previous analyses (Sullivan et al. 2010 and Clark et al. 2011), this stage does *not* include the wellhead apparatus, but instead, all components belowground, including all liners and casings. Pipelines include pipeline, pipeline supports, and support footings.

Stimulation and Circulation Testing stages include consumptive losses from all fluids injected underground for the purposes of stimulating an EGS reservoir and subsequently testing the circulation of this enhanced reservoir. Although additives, such as tracers, diverters, chelating agents, and several others, are present in these fluids (see Clark et al. 2013 for more information on chemicals used in stimulation activities), it was assumed for the purpose of this analysis that the volumes are 100% water. This is because while additives may be present, they typically represent a small percentage of the total fluid sent downhole (Clark et al. 2013).

As mentioned previously, *Belowground Operational Losses*, otherwise known as reservoir loss, were assumed to be either 1% or 5%, depending on the scenario analyzed. These values are based on past research into actual losses at real-world EGS projects, which showed these values to be within the range experienced at these facilities (Chabora et al. 2012; Portier et al. 2009; Zimmermann and Reinicke 2010;

Table 3. Life Cycle Water Consumption Summary for EGS Scenarios[a].

Parameter	**Scenario 1**		**Scenario 2**		**Scenario 3**		**Scenario 4**		**Scenario 5**	
	Reference	Improved	Reference	Improved	Reference	Improved	Reference	Improved	Reference	Improved
	Binary EGS Air-Cooled		Binary EGS Air-Cooled		Binary EGS Air-Cooled		Flash EGS Wet-Cooled		Flash EGS Wet-Cooled	
Capacity (MW)	10	25	15	35	20	40	25	50	30	50
Start year	2012	2030	2012	2030	2012	2030	2012	2030	2012	2030
Well depth (km)	2	2	2.5	2.5	3	3	3.5	3.5	4	4
Temperature (°C)	100	100	150	150	175	175	250	250	325	325
Flow rate (kg/s)	40	100	40	100	40	100	40	80	40	80
Drilling and construction loss (gal/MWh)	9.0 0.21%	2.6 0.28%	2.7 0.27%	0.98 0.32%	2.4 0.29%	0.79 0.34%	2.0 0.07%	0.54 0.02%	1.4 0.07%	0.40 0.03%
Stimulation water consumption (gal/MWh)	32 0.76%	9.3 1.01%	7.8 0.76%	2.8 0.92%	5.8 0.72%	1.9 0.84%	4.7 0.17%	1.2 0.05%	2.9 0.15%	0.8 0.05%
Circulation testing water consumption (gal/MWh)	29 0.69%	8.4 0.91%	7.0 0.69%	2.5 0.83%	5.3 0.65%	1.8 0.76%	4.2 0.15%	1.1 0.05%	2.6 0.14%	0.0 0.00%
Belowground operational loss (gal/MWh)	4,100 97.38%	860 93.48%	960 94.37%	260 84.67%	750 93.36%	190 80.66%	490 17.40%	87 3.98%	270 14.01%	49 3.11%
Cooling-related losses (gal/MWh)	0.0 0.00%	0.0 0.00%	0.0 0.00%	0.0 0.00%	0.0 0.00%	0.0 0.00%	2,300 80.78%	2,048 94.05%	1,600 83.52%	1,500 94.26%
Non-cooling associated consumption (gal/MWh)	40 0.95%	40 4.33%	40 3.92%	40 13.26%	40 4.97%	40 17.40%	40 1.43%	40 1.84%	40 2.11%	40 2.56%
Totals										
Freshwater consumption (gal/MWh)	110	60	58	46	53	44	51	43	47	41
Geofluid loss (gal/MWh)	4,100	860	960	260	750	190	2,700	2,100	1,900	1,500
Geofluid makeup (gal/MWh)	4,100	860	960	260	750	190	2,700	2,100	1,900	1,500
Water consumption (gal/MWh)	4,200	920	1,000	300	800	230	2,800	2,200	1,900	1,600

[a] Geofluid losses may occur aboveground (i.e., flash) or belowground (i.e., EGS). Geofluid is not necessarily lost in all scenarios.
[b] The sum of the percentage contributions of water loss for each life cycle stage may not be 100%, due to rounding.

Table 4. Life Cycle Results for Hydrothermal Scenarios[a].

Parameter	**Scenario 6**		**Scenario 7**		**Scenario 8**		**Scenario 9**		**Scenario 10**	
	Reference	*Improved*	*Reference*	*Improved*	*Reference*	*Improved*	*Reference*	*Improved*	***Reference***	***Improved***
	Binary Hydrothermal Air-Cooled		*Flash Hydrothermal Wet-Cooled*		*Binary Hydrothermal Air-Cooled*		*Flash Hydrothermal Wet-Cooled*		*Binary Hydrothermal Air-Cooled*	
Capacity (MW)	15	20	30	50	30	50	40	50	15	25
Start year	2012	2020	2012	2020	2012	2020	2012	2020	2012	2020
Well depth (km)	1.5	1.5	1.5	1.5	1.5	1.5	2.5	2.5	2.5	2.5
Temperature (°C)	140	140	175	175	175	175	225	225	140	140
Flow rate (kg/s)	100	100	80	80	100	100	80	80	100	100
Drilling and construction loss (gal/MWh)	0.77 1.89%	0.96 2.36%	0.73 1.79%	0.64 1.58%	0.52 1.27%	0.49 1.21%	1.0 2.48%	0.95 2.32%	2.0 4.84%	1.90 4.53%
Stimulation water consumption (gal/MWh)	0.0 0.00%	0.0 0.00%	0.0 0.00%	0.0 0.00%	0.0 0.00%	0.0 0.00%	0.0 0.00%	0.0 0.00%	0.0 0.00%	0.0 0.00%
Circulation testing water consumption (gal/MWh)	0.0 0.00%	0.0 0.00%	0.0 0.00%	0.0 0.00%	0.0 0.00%	0.0 0.00%	0.0 0.00%	0.0 0.00%	0.0 0.00%	0.0 0.00%
Belowground operational loss (gal/MWh)	0.0 0.00%	0.0 0.00%	0.0 0.00%	0.0 0.00%	0.0 0.00%	0.0 0.00%	0.0 0.00%	0.0 0.00%	0.0 0.00%	0.0 0.00%
Cooling-related losses (gal/MWh)	0.0 0.00%	0.0 0.00%	0.0 0.00%	0.0 0.00%	0.0 0.00%	0.0 0.00%	0.0 0.00%	0.0 0.00%	0.0 0.00%	0.0 0.00%
Non-cooling associated consumption (gal/MWh)	40 98.11%	40 97.64%	40 98.21%	40 98.42%	40 98.73%	40 98.79%	40 97.52%	40 97.68%	40 95.16%	40 95.47%
Totals										
Freshwater consumption (gal/MWh)	41	41	41	41	41	40	41	41	42	42
Geofluid loss (gal/MWh)	0.0	0.0	3,600	3,500	0.0	0.0	2,600	2,500	0.0	0.0
Geofluid makeup (gal/MWh)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Water consumption (gal/MWh)	41	41	41	41	41	40	41	41	42	42

[a] *Geofluid losses may occur aboveground (i.e., flash) or belowground (i.e., EGS). Geofluid is not necessarily lost in all scenarios.*
[b] *The sum of the percentage contributions of water loss for each life cycle stage may not be 100%, due to rounding.*

Schindler et al. 2010). Although higher loss rates have been observed at feasibility testing sites, it is unlikely that utility-scale projects would be practical at high loss rates.

Finally, aboveground operational losses are represented by two distinct categories: Cooling-Related Losses and Non-Cooling Associated Loss. *Cooling-Related Losses* include all water consumed during cooling-related operations of the plant itself, while *Non-Cooling Associated Losses* are meant to encompass all other losses not included in the other life cycle stages. Non-Cooling Associated Loss is assigned a constant value of 40 gallons per MW. This value is based on the average water consumption of a dry-cooled binary system, which, because the cooling system does not consume any water, represents the water consumption from non-cooling related activities, such as dust suppression, maintenance, and domestic use (BLM 2010; CEC 2008; DOE 2011b; Geodynamics 2011; Kagel et al. 2005).

Results and Discussion

Life cycle results are summarized in Tables 3 and 4. Table 3 summarizes water consumption by life cycle stage for EGS scenarios, and Table 4 does the same for hydrothermal scenarios. A few key parameters, such as capacity, well depth, temperature, flow rate, and cooling technology, are included at the top of each scenario. In addition, the percentage of total consumption that each life cycle stage represents is given beneath the respective quantity.

Operational Losses Versus Construction and Drilling Losses

Overall, the water loss for the construction and drilling phase was found to be extremely small when compared with the total water loss for all scenarios analyzed. For the EGS scenarios, consumptive losses from drilling and construction accounted for between 0.02% and 0.34% of the total water consumption for each scenario. These percentages went up slightly for the hydrothermal scenarios, with well drilling and construction making up 1.2% to 4.8% of total water consumption. These findings are in line with previous findings, which suggest that operational losses are by far the major contributor to geothermal water consumption (Clark et al. 2011, 2013).

Binary EGS Versus Flash EGS

In all EGS scenarios, losses from the operational phase, both aboveground and belowground, accounted for most of the water consumption. For the air-cooled binary EGS scenarios, belowground reservoir loss dominated and accounted for 80.6% to 97.4% of the total water consumption. For wet-cooled flash EGS scenarios, aboveground operational losses dominated. This finding is due to significant cooling-related losses in the flash system scenarios, which account for between approximately 80.8% and 94.3% of total water consumed, depending on the scenario, according to GETEM. These losses occur because of (1) flashing of the geofluid and incomplete condensing of the fluid, and (2) the wet cooling system assumption used for these systems, i.e., that a portion of the produced geofluid condensate will be diverted to cool the system. Some of the condensate used for cooling water is lost via the cooling tower through blowdown, drift, or evaporative losses. Binary systems that are air-cooled do not experience these losses. The cooling-related losses are significant in EGS, as any geofluid lost from the system must be replaced to maintain sufficient reservoir pressures belowground.

Binary Hydrothermal Versus Flash Hydrothermal

For binary hydrothermal scenarios, non-cooling associated losses dominated at greater than 95% for all scenarios. In contrast, for flash hydrothermal scenarios, there is significant fluid loss due to cooling. This fluid loss appears in Table 4 not under cooling-related losses, but under geofluid loss, and ranges between 2,500 and 3,600 gal/MWh. Unlike other thermoelectric power generation technologies (e.g., coal, natural gas, or nuclear), flash geothermal systems typically rely on condensate, not freshwater, for cooling. As a result, no freshwater consumption due to cooling is reported in Table 4 for the flash hydrothermal scenarios.

Although this reliance on geofluid condensate leaves the long-term sustainability of the reservoir vulnerable, it is a common industry practice to not replace the lost geofluid or to replace only a fraction of lost geofluid. Therefore, one can see in Table 4 that for those systems, geofluid losses were high, but total freshwater consumption was actually very low, particularly when compared to EGS. However, at least two operating flash hydrothermal plants, Coso and Dixie Valley, do have existing supplementary injection augmentation programs that utilize fresh groundwater to make up for lost geofluid (BLM and U.S. Navy 2008; NDWR 2012). In these cases, freshwater consumption is significantly higher, approaching the quantity of geofluid lost.

Hydrothermal Water Losses Versus EGS Water Losses

As mentioned previously, the differences in water consumption between the EGS and hydrothermal scenarios were largely due to the differences inherent in these two technologies. EGS projects must first inject water underground to create a reservoir. Maintaining sufficient reservoir volume and pressure to successfully circulate fluid requires significant volumes of water through the life of the project, as, according to literature reviews on this topic conducted previously, belowground fluid losses are expected to vary from 1% to 10% (Clark et al. 2013). In contrast, hydrothermal systems do not have this issue. Binary hydrothermal systems, which can rely on air-cooling, consume relatively little water.

In comparing water consumption between these technologies, the model shows that binary EGS systems consume between 230 and 4,200 gal/MWh over the life cycle, whereas binary hydrothermal systems consume between 40 and 42 gal/MWh. For flash systems, this difference between hydrothermal and EGS resources is also very pronounced, as much of the fluid loss in the hydrothermal scenarios is attributable to geofluid loss and not to actual freshwater consumption. Flash hydrothermal water consumption is 41 gal/MWh, and flash EGS water consumption ranges from 1,600 to 2,800 gal/MWh. However, this difference will shrink significantly for flash hydrothermal systems where makeup fluid is injected to improve the sustainability of the reservoir. This process was not directly modeled, but the quantity of water that would be required can be inferred from the calculated total geofluid loss values presented in Table 4 and ranges from 2,500 to 3,600 gal/MWh.

Impact of Resource Temperature

Lower temperature resources require higher total flow rates to generate the same amount of energy. This fact directly affects two variables that impact water consumption—belowground operational losses for EGS and the number of wells required to generate the same amount of power. Given that operational losses make up the majority of water consumption for most geothermal systems, the impact on belowground operational losses is far more significant for the overall water requirements than the impact of the number of wells drilled. For EGS where the resource temperature is high enough that flash systems are recommended or required, the water consumption is typically greater than for binary EGS because of the additional aboveground operational losses associated with the wet-cooled flash systems, which are

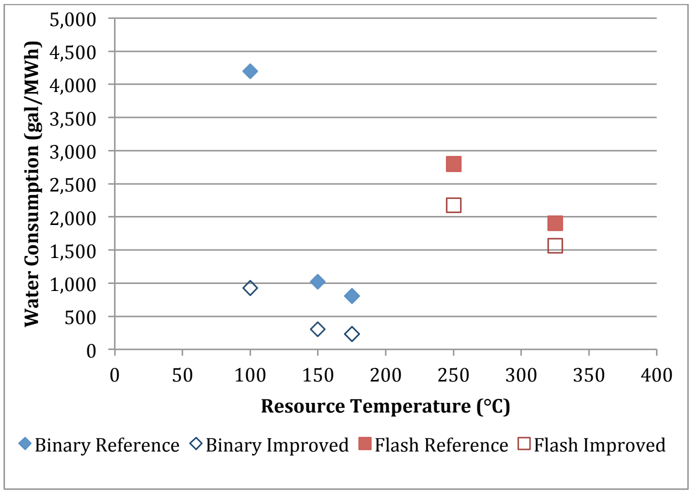

Figure 1. Water Consumption for EGS as a Function ofResource Temperature.

typical for systems with higher resource temperatures. Figure 1 illustrates these phenomena by plotting the results of the EGS scenarios as a function of resource temperature. An exception to this pattern is seen in the high water consumption of the low-flow rate per well, low-temperature binary EGS scenario, which requires a high throughput of fluid for power generation, ultimately resulting in much greater belowground water consumption than other scenarios.

Total Consumption by Fluid Type

Figures 2 and 3 illustrate the water consumption for the Reference and Improved scenarios, respectively, as a function of fluid type. Three different fluids were considered—freshwater, formation-compatible water, and geofluid. Water consumed for drilling, stimulation, and aboveground non-cooling operational uses was assumed to be freshwater. However, water injected into the formation to compensate for aboveground or belowground operational losses need not be fresh and must only be chemically compatible with the formation and the injection well materials. Thus, it is possible that many degraded or lower-quality water sources can be utilized for these purposes, thereby reducing the impact of geothermal systems on freshwater resources. In Figures 2 and 3, this water is classified as "any water." Potential alternative water sources that could be used for this purpose include, but are not limited to, municipal or industrial wastewater, brackish or saline groundwater, and impaired surface waters. For example, the Geysers geothermal field utilizes municipal wastewater piped from nearby municipalities to make up for aboveground operational fluid losses (Calpine Corporation 2014). Finally, geofluid consumption, while not having a direct impact on freshwater resources, does have an impact on the sustainability of the geothermal resource and is thus treated as a separate category.

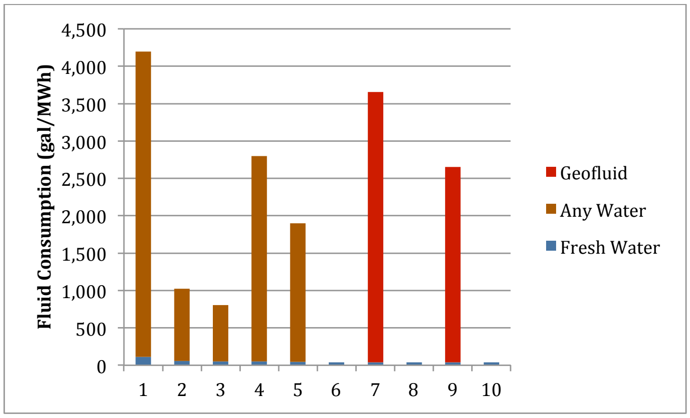

Figure 2. Total Fluid Consumption by Fluid Type for Reference Scenarios (EGS Scenarios 1–5; Hydrothermal Scenarios 6–10).

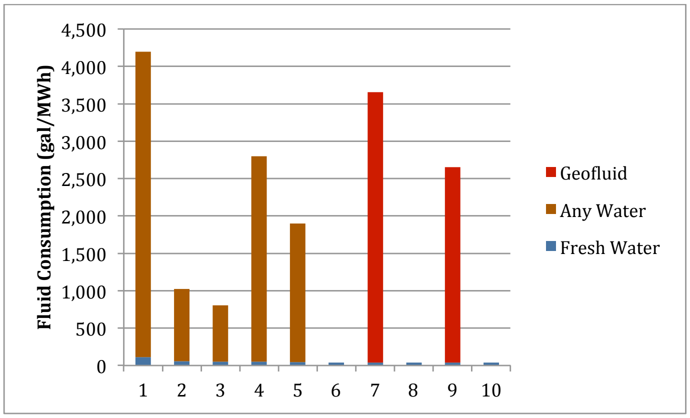

Figure 3. Total Fluid Consumption by Fluid Type for Improved Scenarios (EGS Scenarios 1–5; Hydrothermal Scenarios 6–10).

The results show that although total fluid consumption for most scenarios is quite high relative to most energy systems, with a low of 40 gal/MWh for binary hydrothermal systems and a high of 4,200 gal/MWh for binary EGS, the consumption of fluid that would typically be freshwater for most of the scenarios is approximately 40 to 50 gal/MWh, which is significantly less than most thermoelectric generation technologies and on par with other renewables such as solar and wind. Please refer to Table 5 below for this analysis.

Table 5. Comparison of Water Consumption by Energy Technology,

Energy Technology	Water Consumption *(gal/MWh)*
Geothermal (binary hydrothermal)[*]	40
Geothermal (flash hydrothermal)[*]	40[**]
Geothermal (binary EGS)[*]	230–4,200
Geothermal (flash EGS)[*]	1,600–2,800
Geothermal (freshwater average)[*]	40–50
Geothermal (Meldrum) [1]	5–720
Wind [1, 2]	1–10
Solar (PV) [3, 4, 5]	70–190
Solar (CSP) [1, 3, 4, 5]	160–1,120
Coal [4]	100–1,100
Nuclear [4]	100–845
Conventional Natural Gas [1, 6]	9–730
Shale Gas [1, 6]	21–730

[*] From this analysis
[**] Only includes freshwater, not geofluid consumption
[1] Meldrum et al. 2013
[2] Vestas Wind Systems A/S et al. 2006
[3] Harto et al. 2010
[4] Macknick et al. 2011
[5] DeMeo and Galdo 1997
[6] Clark, Horner, and Harto 2013

More recent attempts at estimation and harmonization of literature estimates for renewable energy technologies by Meldrum et al. (2013) show freshwater consumption by geothermal technologies to be between 5 and 720 gal/MWh, depending on the configuration of the plant (e.g., flash hydrothermal, binary hydrothermal, or EGS) and the cooling technology employed (e.g., air-cooled, hybrid-cooled, or water-cooled) (Meldrum et al. 2013). Their analysis specifically excludes water from internal sources, such as geofluid consumption. It is worth noting that when one looks at only freshwater consumption, all of the scenarios presented here fit within the range presented by Meldrum.

In comparing water consumption between the Reference and Improved scenarios, it becomes apparent that although water consumption for the hydrothermal scenarios is fixed at approximately 40 gal/MWh, owing to the non-cooling-associated consumption discussed previously, the Improved case shows significant water savings relative to the Reference case for the EGS scenarios. This finding is largely due to improved control of the reservoir in the Improved scenarios. Reservoir loss drops from 5% in the Reference case to 1% in the Improved case, and since this loss is the largest contributor to water consumption for EGS, it follows that improving it would positively affect the water consumption numbers, as indeed is the case here.

Summary and Conclusions

The geothermal water life cycle scenarios previously developed have been updated to be consistent with the current LCOE scenarios used by GTO. These scenarios include a more complete exploration of the parameter space of possible geothermal power plants and allow for a more thorough examination of the impact of key factors on life cycle water consumption. The most influential of these factors (outside of technology selection) was shown to be resource temperature. In general, higher resource temperatures result in lower water consumption for the same technology; however, in general and with the exception of the low-temperature, low-flow binary EGS scenario, going from binary EGS that typically operate at lower temperatures to flash EGS that operate at higher temperatures results in a large jump in the aboveground operational loss of geofluid. In most hydrothermal systems, this additional loss of geofluid is not replaced; this unreplaced loss does not increase water consumption, but it does have long-term impacts on the sustainability of the reservoir. However, in EGS, this lost geofluid will more than likely need to be replaced to maintain reservoir pressure. The use of alternative, lower-quality water sources will be important in these cases because of the high water requirements relative to competing electricity generation systems.

This analysis also highlights the impact of reservoir performance on water consumption for geothermal energy systems. Technology improvements that can reduce belowground operational loss to 1%, as modeled in the Improved EGS scenarios, can significantly reduce overall water consumption when compared to Reference scenario loss rates of 5%. Another option for reducing water impacts would be the use of air-cooled binary systems for higher-temperature EGS resources than are typical for hydrothermal resources, which would eliminate high cooling-related water losses. This option is likely to be most viable for EGS resources of more than 200°C but lower than 300°C. An example of a higher-temperature hydrothermal reservoir currently supporting a binary system is the 24-MW binary facility that Ormat operates in Zunil, Guatemala, which has a resource temperature of 300°C (GRC 2003).

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