Proceedings World Geothermal Congress 2015
Melbourne, Australia, 19-25 April 2015

Cost Contributors to Geothermal Power Generation

Jay Nathwani[1] and Greg Mines[2]

[1]United States Department of Energy; [2]Idaho National Laboratory

[1]Jay.Nathwani@ee.doe.gov; [2]Gregory.Mines@inl.gov

Keywords: power generation costs, enhanced geothermal systems, hydrothermal

ABSTRACT

The US Department of Energy Geothermal Technologies Office (DOE-GTO) has developed the tool Geothermal Electricity Technologies Evaluation Model (GETEM) to assess the levelized cost of electricity (LCOE) of power produced from geothermal resources. Recently modifications to GETEM allow the DOE-GTO to better assess how different factors impact the generation costs, including initial project risk, time required to complete a development, and development size. The model characterizes the costs associated with project risk by including the costs to evaluate and drill those sites that are considered but not developed for commercial power generation, as well as to assign higher costs to finance those activities having more risk. This paper discusses how the important parameters impact the magnitude project costs for different project scenarios. The cost distributions presented include capital cost recovery for the exploration, confirmation, well field completion and power plant construction, as well as the operation and maintenance (O&M) costs. The paper will present these cost distributions for both EGS and hydrothermal resources.

1. INTRODUCTION

In the mid 2000's the US DOE Geothermal Technologies Office (GTO) developed GETEM as a tool that could both identify major contributors to generation costs and provide a method of assessing how technology could impact those costs (Entingh, 2006). In using the model, a user defines both the resource conditions and the scenario under which the resource is developed for power generation. Based on the user input, the model determines the size of the well field and power plant and estimates those capital costs. The model's estimates are to be 'representative' of the costs that would be encountered in the defined resource scenario using either air-cooled binary or flash steam technologies for the power plant. The initial focus of model development was on the generation costs from hydrothermal resources. In subsequent work importance was placed on the improving the model's functionality to calculate detailed cost and performance estimates for each of the project phases for the different geothermal resources in GTO's decision processes.

In 2011, a DOE-selected Blue Ribbon panel of US geothermal experts provided feedback that generation costs used in the GTO's planning were not representative of the actual costs of new projects, and recommended DOE verify and validate the data, assumptions and methodology used in GETEM to prepare its estimates. An area where the costs estimates were considered too low was for those activities associated with resource exploration, and confirming that the discovered resource is commercially viable. The GTO assembled a team that included national laboratory and contractor personnel to make a concerted effort to improve the model's characterization of cost and performance for all project development phases for both undiscovered hydrothermal and EGS resources. During this effort, international geothermal experts were interviewed and the model revised so that its estimates reflected the expert opinion. Comments were subsequently solicited from geothermal industry on the cost and performance estimates produced by the model.

When this effort concluded, the level of model input was too onerous for most users. To simplify the model's use, default inputs were established that were functions of a defined resource temperature, depth and type (hydrothermal or EGS). With these 3 parameters defined, the model will estimate a power generation cost using the defaults. A user has the option of changing several of these defaults, and the model will utilize those changes to estimate a revised generation cost. This version of the model is available to the public, and can be found at the DOE GTO web site (http://energy.gov/eere/geothermal/geothermal-technologies-office).

2. MODEL APPROACH

To estimate LCOE's for a particular scenario, the model establishes the capital costs for four project phases: exploration/discovery, resource confirmation, well field completion, and power plant design and construction. The model also estimates the operating and maintenance (O&M) costs, as well as the pumping power needed for both production and injection of the geothermal fluid.

2.1 Exploration and Confirmation

The model's estimate of the costs for the exploration or discovery project phase are not calculated per se, rather they are based largely on default values for costs; many of these default values can be revised by the user. In order to characterize the risk associated with discovering a commercially viable resource, the model utilizes a project selection process that is depicted in Figure 1. Using this methodology with green-field hydrothermal resources, one would evaluate multiple locations before drilling any wells. Exploratory drilling could occur at multiple locations, with some of those locations failing to discovery any resource potential. One or more of these sites would have additional drilling to confirm the commercial potential of the resource. From these sites having confirmation drilling, one successful location would be identified and a power plant developed at that site. In determining the generation cost for the successful project site, costs are included for all 'failed' sites that were evaluated and drilled in the exploration and confirmation phases.

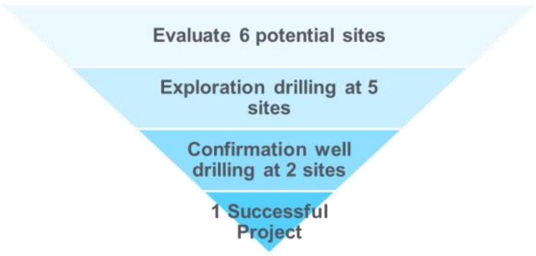

Figure 1. Project Selection Methodology

A user can revise the several of the default values the model uses, including the number of locations or sites considered in both the exploration and confirmation activities.

The model assumes all wells drilled during the confirmation phase are 'full-sized' wells, and that these wells have a higher cost than the wells subsequently drilled when the well field is completed (i.e., there is a learning curve associated with drilling the wells in this field). The model assumes that the wells drilled at all confirmation sites have the same depth as the resource at the successful site. When evaluating EGS resources, the model assumes that at least one of the wells drilled is stimulated at the sites having confirmation drilling.

2.2 Well Field Completion

The model determines the size of the well field that is required to provide a desired level of power sales. The magnitude of the power sales is the difference between the net plant output and the geothermal pumping power. The number of required production wells is a function of the sales, the production well flow rate, the geothermal pumping power and the plant performance metric (net plant output per unit flow rate). The number of injection wells required is determined using the calculated production well count and the default (or revised) value for the ratio of production to injection wells. The number of wells needed in order to complete the well field are the number of required wells less the successful confirmation wells. The total number of wells drilled during this phase is based on the number needed and the drilling success rate used (default or revised).

The model uses two different cost curves to estimate the well drilling cost. Those curves are based upon the well depth, and whether the well is a 'larger' or 'smaller' diameter well. The smaller diameter well will have a minimum bottom hole diameter of 21.6 cm, while a larger diameter well will have a minimum bottom hole diameter of 31 cm. The costs for the two well configurations are based on estimates generated by Sandia National Laboratory. The wells costs for the configurations are shown as a function of depth in Figure 2 along with the well costs from several sources, including the interviews with the US geothermal industry.

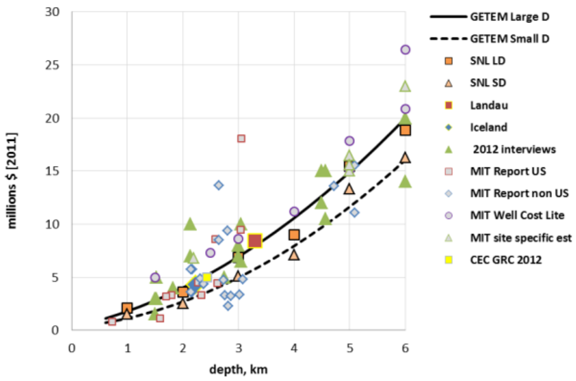

Figure 2. Well Cost Curves in GETEM

Included in the well field completion costs are the costs for the surface equipment (based on the total number of wells required), as well as the costs for the geothermal production and injection pumps.

2.3 Power Plant

GETEM evaluates either flash-steam or air-cooled binary power plants; it does not estimate costs or performance for water-cooled binary plants. Flash-steam plants can be either single or dual flash. Flash pressures used in the model are based on the methodology given by DiPippo (2012) for approximating the optimal flash temperatures. Those pressures, as well as the default values for the ambient wet bulb and noncondensable gas levels, can be revised. The model determines the capital costs based on the equipment sizes estimated for the plant output needed to provide the level of power sales for a particular scenario.

While the flash-steam plant cost is based upon both the resource temperature and the size of the plant required, the model's estimate of the air-cooled binary plant cost accounts for the tradeoff made by the plant designer between performance and cost. Plants that more efficiently convert the energy (available energy or exergy) in the geothermal fluid into power are more equipment intensive and have higher capital costs. When GETEM establishes the binary plant performance, it performs this tradeoff; as plant performance (2nd law efficiency) increases, the plant cost in terms of $/kW of plant output increases and the flow required decreases. With an increasing brine utilization (2nd law efficiency) the flow required to generate a specific level of sales decreases, which decreases the costs associated with the well field decrease. This tradeoff is depicted in Figure 3, which shows the impact of plant performance on both the total and plant capital costs per MW of power sales for a 30 MW air-cooled binary plant using a 200°C hydrothermal resource. The higher plant capital costs shown at the lower levels of plant performance are the consequence of having to build a larger plant in order to both satisfy the geothermal pumping requirements and provide the 30 MW of sales. As the performance metric increases, the costs associated with the well field (the difference between the total cost and the plant cost) decreases, as does the geothermal pumping power (plant size is approaching the 30 MW of sales). At some level of performance, the increase in plant cost offsets the corresponding decrease in the well field costs, and total costs rise. When GETEM solves for plant performance it performs the trade- off between the plant performance and the contribution of the capital costs to the LCOE to find the minimum generation cost.

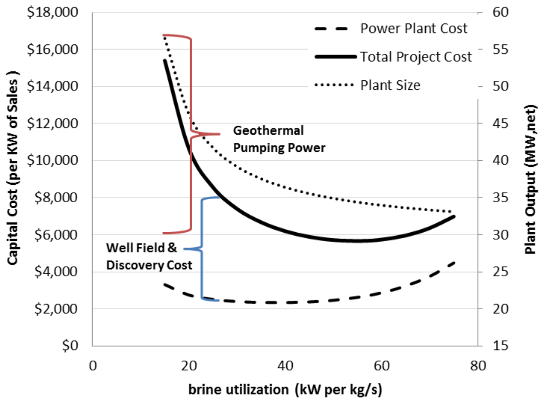

Figure 3. Effect of performance on costs in air-cooled binary plant with 30 MW sales

GETEM's cost correlations for the equipment in a binary plant are based on the 2nd law efficiency, the plant size and the resource temperature. The brine utilization shown in Figure is in the numerator of the 2nd law efficiency, while the denominator is the available energy based on an ambient air temperature of 10°C (approximately mean average air temperature in U.S.). The capital cost for the plant is based upon its net output, which accounts for the parasitic losses within the plant but not the geothermal pumping; it is sum of the specified power sales and the calculated geothermal pumping power. In estimating the cost of the turbine-generator, GETEM does estimate the in plant parasitic loads and adds those loads to the net output to establish the turbine-generator size required.

2.4 Geothermal Reservoir

The model has default values that can be revised for several parameters used to depict the geothermal reservoir performance; they include the flow rate per production well, the annual rate of temperature decline, the Productivity/Injectivity Indices, and with EGS resources the subsurface water losses. The well flow rate and Productivity/Injectivity Indices are used to determine the geothermal pumping power, that is used with the plant performance metric (brine utilization or brine effectiveness) to establish the total production flow needed to meet the target power sales. This total flow rate and the flow rate per production well define the number of wells required.

The annual rate of temperature decline is used to depict the effect of a declining resource temperature on the power generated and available for sales. The model has correlations that relate the effect of a declining resource temperature on the plant conversion efficiency (2nd law) for both flash-steam and binary plants. This conversion efficiency and the available energy calculated for the declining resource temperature are used to predict the power sales throughout the life of the plant. These calculations assume that the total geothermal fluid production flow remains constant. If the resource temperature decline reaches the maximum allowed, the model assumes that the entire well field is replaced and the resource temperature returns to the initial value defined. This replacement occurs provided that the plant is not in the last 5 years of its defined life, and that sufficient resource potential was found during the exploration/discovery phase. The model default for resource potential allows for one well field replacement during the project life; this default can be revised. The cost for the well field replacement is included in the estimate of generation cost.

2.5 Operation and Maintenance Costs

GETEM's estimates for the operating and maintenance (O&M) costs are based upon the plant size and the type of conversion system used. The plant size used is the net plant output – not the power sales. Annual labor costs are based on staff manpower levels that are based on size and type of plant. Annual maintenance costs are determined as a percentage of the capital costs for the well field and power plant. If production pumps are used, the maintenance costs also include costs to replace those pumps at regular intervals throughout the project life. The estimates for the annual O&M costs also includes taxes and insurance, as well as royalties. As the default, model uses the U.S. Department of Interior, Bureau of Land Management (BLM) royalty schedule.

The model has default values used for the different parameters used to calculate these O&M costs. Most of these parameters can be revised by a model user.

2.6 Model Limitations

The model's estimates are based on correlations that were developed over an anticipated range of conditions, and while the model will provide estimates outside of those ranges, those estimates may not be representative of costs that would be encountered. For example, the well cost curves are based on estimates made up to depths of 6 km. While greater depths can be estimated, there is no basis for those estimates. Similarly plant cost estimates were developed for sizes larger than 3 MW for binary and 10 MW for flash; the model will estimate costs for smaller plants, but again there is no basis for those estimates.

The model does not estimate the costs for water-cooled binary plants. Cost and performance estimates for the binary plants are based on an ambient temperature of 10°C; this value can not be changed. The model also uses curve fits of the properties of pure water in its calculations of cost and performance.

3. POWER GENERATION COST CALCULATION

GETEM calculates a levelized-cost-of-electricy (LCOE) based upon the estimated capital and O&M costs and the projected plant output over the project life. This LCOE represents the price of electricity needed to recover the capital costs and meet O&M costs. It does not provide for profit. The model's estimates for different costs are based on correlations that are referenced to a particular year. To account for changes that have occurred since that reference year, Producer Price Indices (PPI's) are applied to the estimated costs. These PPI's are taken from the U.S. Department of Labor's Bureau of Labor Statistics. The PPI's are not automatically updated as they become available.

3.1 Pre-Startup Costs

GETEM utilizes a schedule for all project development phases. Costs for a particular phase are spread evenly over the duration of that particular phase. A discount rate is then applied to those costs annually until the start of operation to provide the present value of those costs when the revenue stream from sales begins. The discount rate reflects the financing cost for that particular phase. The model assumes that permitting activities for the project phases is done prior to costs being incurred for those phases. The exploration phase and the confirmation phase activities are assumed to be permitted under a single permit that is obtained prior to the start of the exploration phase. Similarly the well field completion and power plant construction and operation are covered by a single permit that is obtained before work on either is done. All activities are assumed to occur in series, with the exception of both the permit for the well field and power plant, which is assumed to occur concurrently with the confirmation phase, and the well field completion and power plant construction, which are assumed to occur concurrently. Table 1 shows the default values used by the model for the phase duration and discount rates with a hydrothermal resource using an air-cooled binary plant.

Table 1. Pre-startup schedule and discount rates for Hydrothermal Binary

Activity	Duration	Discount Rate
Permitting – Exploration & Confirmation	**1 yr**	**30%**
Exploration	**2 yr**	**30%**
Confirmation	**1.5 yr**	**30%**
Permitting – Well Field & Power Plant	**1**	**15%**
Well Field Completion	**1.5 yr**	**15%**
Power Plant Installation	**2 yr**	**7%**
Total Pre-Startup	**6.5 yr**	

Costs incurred at the failed, or unsuccessful, exploration and confirmation sites are included in the total project costs used in calculating the generation costs. Because of the higher discount rates applied to these early project costs, they have a significant impact on the LCOE that is determined. These costs represent the risk, or uncertainty associated with discovering a commercially viable resource. The capital costs also include a contingency that is applied to all phases of the project development.

3.2 Post Startup Cost and Revenues

Costs that are incurred subsequent to startup are discounted at a fixed rate to determine the present value of those costs. These costs include the O&M costs, property taxes and insurance, royalties, taxes on revenues, and any well field replacement costs.

The revenues for the power sales are also discounted. These revenues include the impact of any decline in resource productivity on power generation; the decline in productivity is depicted in the model as a decline in resource temperature. Revenues also the impact of the outages that occur during a year, as well as the effect of varying ambient conditions. This is accomplished by applying a 'utilization factor' to the estimated plant output. This factor is effectively the net capacity factor for the plant at design, or the ration of the net generation during the year to the generation of the plant had operated continuously at its design net output.

3.3 LCOE Calculation

In its calculation of generation costs, GETEM utilizes fractional wells, equipment items, and staff.

The LCOE calculation utilizes a methodology that replicates a discounted cash flow analysis. It is based on the present value of capital costs, operating costs, and sales revenues at the start of operation. The model has default values for the project life of both hydrothermal (30 yr) and EGS resources (20 yr). These default values can be revised to up to 40 yr when the simple discounted cash flow is used to determine the LCOE. (The model does allow the LCOE to be determined using a Fixed Charge Rate; if used a 30 year project life must also be used,)

4.0 MODEL ESTIMATES OF FACILITY AND GENERATION COST

GETEM's estimates are based on a specific, defined scenario. In the following discussion, the impact of several parameters on cost is estimated, including the conversion system, resource type, resource temperature and depth.

4.1 Resource and Conversion System

In Tables 2 and 3, three scenarios are defined that show the impact of the resource type and conversion system on project costs. For the hydrothermal scenario, estimates are given for a representative flash plant and air-cooled binary plant. For all scenarios, it is assumed that Exploration and Confirmation is done only at the final site (no costs included for unsuccessful sites).

Table 2. Scenario Parameters for Hydrothermal and EGS Resources

Scenario	Hydrothermal Flash	Hydothermal Bainary	EGS BinaryFlash 3
Temperature [°C]	**200**	**200**	**175**
Depth [km]	**2**	**2**	**3**
Sales [MW]	**30**	**30**	**20**
Project Life [yr]	**30**	**30**	**20**
Well Flow [kg/s]	**80**	**100**	**40**
Plant Size [MW]	**31.4**	**32.6**	**20.3**
Production Wells Required	**5.8**	**4.3**	**7.8**
Injection Wells Required	**4.3**	**3.2**	**3.9**
Total Wells Drilled	**13.9**	**10.7**	**11.7**

Table 3. Scenario Cost for Hydrothermal and EGS Resources

Scenario	Hydro-Flash	Hydro-Binaray	EGS-Binary
Temperature [°C]	**200**	**200**	**175**
Depth [km]	**2**	**2**	**3**
Levelized Cost of Electricity (per kW-hr)	**$0.109**	**$0.101**	**$0.234**
Annual Operating Cost Contribution to LCOE (per kW-hr)	**$0.024**	**$0.022**	**$0.048**
Exploration ($M)	**$3.704**	**$3.699**	**$2.076**
Confirmation ($M)	**$29.196**	**$29.196**	**$30.301**
Well-Field Completion ($M)	**$49.913**	**$33.461**	**$88.715**
Power Plant ($M)	**$71.078**	**$64.930**	**$64.423**
Overnight Capital ($M)	**$155.501**	**$132.897**	**$190.029**
Overnight Capital with contingency ($M)	**$178.826**	**$152.831**	**$218.534**
Present Value Capital Costs at Startup ($M)	**$210.411**	**$196.511**	**$267.370**
Operation & Maintenance ($M/yr)	**$3.625**	**$3.373**	**$5.606**
Taxes & Insurance ($M/yr)	**$1.091**	**$0.929**	**$1.559**
Royalties: 1st yr ($M/yr)	**$0.474**	**$0.441**	**$0.682**
Annual Operating Cost ($M/yr)	**$5.189**	**$4.744**	**$7.847**

The estimated costs for the binary plant are less than those for the flash plant with the 200°C hydrothermal resource. Those costs are lower because the binary plant has a higher 2nd law conversion efficiency which results less fluid being required to produce the 30 MW of sales, even though a larger binary plant is needed to produce that level of sales. With decreased flow, fewer wells are needed, lowering the costs to complete the well field, as well as the total project costs. For the two hydrothermal resource scenarios, the exploration and confirmation costs are effectively equivalent. This is because the methodology that GETEM uses assumes that during these phases similar activities and costs will be incurred regardless of the type of plant used or the size of the plant that is subsequently developed. These costs vary from scenario to scenario only when the well depth and drilling costs change.

Note that even though the binary EGS power plant is smaller (20.3 MW vs 32.6 MW) than the hydrothermal binary plant, their estimated plant costs are nearly the same. This occurred because GETEM assumes a more efficient and costly power plant in order to reduce the number of wells required and minimize the project cost.

For the EGS scenario, the model assumes that all injection wells are stimulated, and that the stimulation cost is $2.5M.

4.2 Resource Temperature and Depth

The effects of resource temperature on the overnight capital costs and power generation costs for the hydrothermal flash-steam and air-cooled binary plants are shown in Figure 4. The power sales, flow rates, and depths are consistent with the hydrothermal scenarios shown in Table 2.

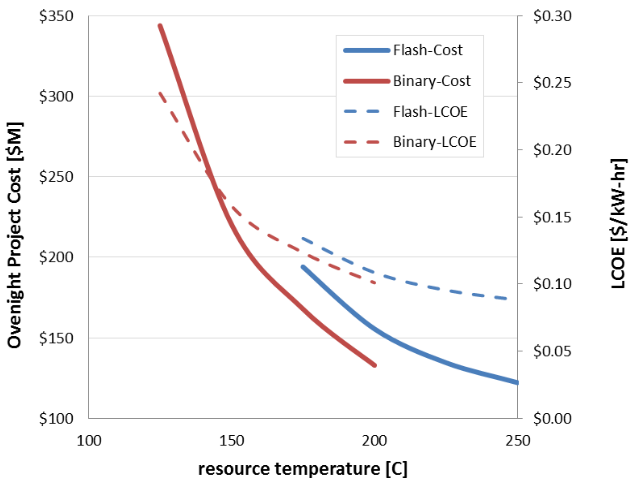

Figure 4. Effect of Resource Temperature on Cost

The impact of temperature on cost is significant. Higher temperature resources have the potential (available energy) to provide more power output per unit flow rate. Provided conversion efficiencies (2^{nd} law) do not decrease, this higher potential lowers the flow requirements to produce a specified power sales. The reduced flow decreases the size and cost of the well field, resulting in the lower capital and generation costs as shown. Temperatures higher than 200°C were not considered for the hydrothermal binary plant. This represents the upper limit for GETEM's cost and performance correlations for air-cooled binary plants. It also represents an upper temperature limit for current electric submersible production pump technology.

The effects of the resource depth on overnight capital costs and power generation costs are shown Figure 5 for hydrothermal binary and flash plants. Again the power sales, flow rates and resource temperatures are consistent with the hydrothermal scenarios in Table 2.

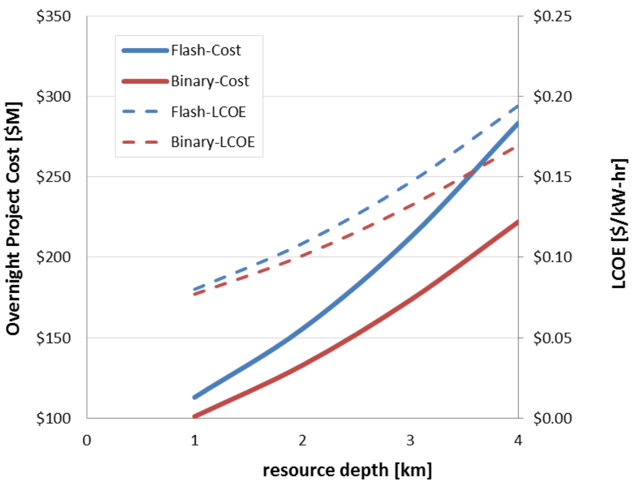

Figure 5. Effect of Resource Depth on Cost

Because the resource temperature is constant, the increased cost with depth is attributable to the additional drilling costs that are incurred. The estimated costs of the binary plant do not increase at the same rate as those for the flash plant because the trade-off the model performs to establish the cost and performance of the binary plant, a more efficient plant is being used with increasing depth. This more efficient plant reduces the number of wells required from 8.1 at a depth of 1 km to 6.8 wells at 4 km.

4.3 Project Size

The effect of project size (power sales) on generation costs is shown in Figure 6. The scenarios in this figure are as defined in Table 2, with the exception of the power sales. Generation costs increase for the smaller plant size largely because GETEM assumes that the exploration costs for a project remain constant at a given resource, regardless of the project size. This is based on the premise that at the beginning of a project when these costs are incurred, the developer does not know the level of power sales that will be supported by the resource discovered. Because their costs have to be recovered from the sales revenues, the LCOE contributions from these two activities increase as the level of sales decreases.

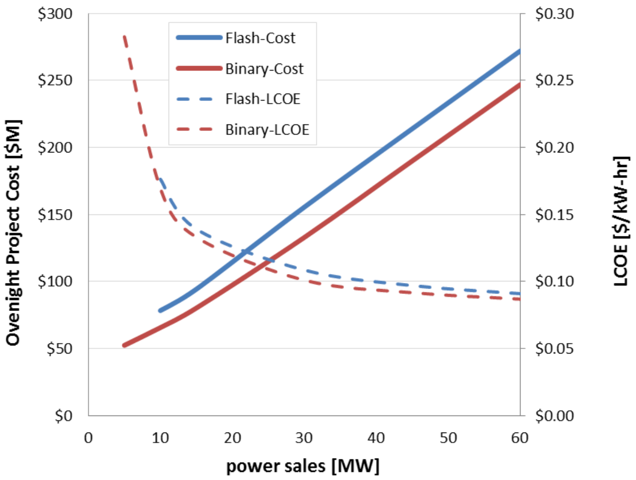

Figure 6. Effect of Project Size on Costs

The model does estimate higher plant costs, in terms of $/kW, as the size decreases, however their effect in increasing the LCOE with decreasing plant size is secondary to the effect of the fixed costs for exploration and confirmation.

4.4 Production Well Flow

Project costs are a function of the productivity of the resource. GETEM depicts this productivity using a combination of parameters that reflect the reservoir productivity. These parameters are the temperature decline rate, the productivity/injectivity indices and the well flow rate. In Figure 7, the impact of a varying well flow rate on costs is shown for the hydrothermal scenarios defined in Table 2. For the estimates shown in this figure, the temperature decline is fixed at 0.4% per year and the Productivity and Injectivity Index are both at 4.57 kg/s per bar. Neither of these parameters change with flow rate.

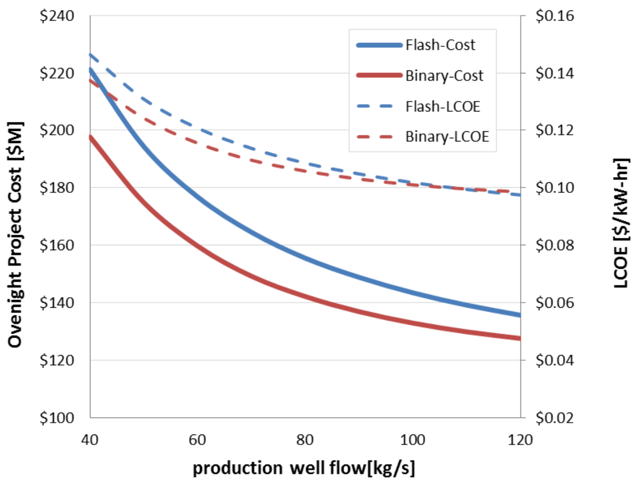

Figure 7. Effect of Production Well Flow on Cost

The model's estimates shown in Figure 7 are indicative of how reservoir productivity (in this example, production well flow) affects project cost. For the 30 MW power sales, the size and cost of the well field decreases with the increasing flow rate.

Increased flow does impact the amount of geothermal pumping power that is required, and at some point the added costs associated with the increased pumping may off-set the benefit of increasing the flow. This is not apparent in Figure 7, though under scenarios with lower Productivity/Injectivity Indices, it can occur.

4.5 Drilling Success Rate

During the confirmation phase, GETEM assumes a drilling success rate of 60%, and that those successful wells will subsequently support the operation of the power plant, either as injection or production wells. During the completion of the well field, GETEM utilizes a higher drilling success rate under the premise that there is a learning curve within a given field, and as more wells are drilled, the success rate will increase. In Figure 8, the effect of the success rate during the completion of the well field on project costs is shown for both hydrothermal scenarios in Table 2. In this figure the success rate is varied from the 60% used during the confirmation phase up to 100%.

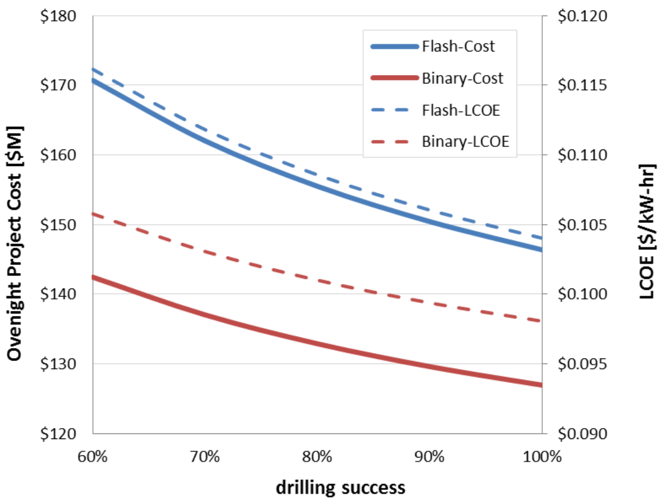

Figure 8. Effect of Drilling Success on Cost

Increased success rate does lower project costs. The degree to which costs are decreased will be dependent upon the cost of well field relative to that of the power plant and the initial exploration and confirmation costs. As the magnitude of well field costs relative to these other costs increase, so too will the impact of increased drilling success rates. The size of the project will also impact the impact of increased success rate on cost. With larger projects, more wells are required, and increased drilling success rate will have a increasing impact on decreasing the LCOE and project costs.

4.6 Number of Exploration and Confirmation Sites

GETEM allows for the inclusion of the costs for those exploration and confirmation sites that were evaluated and drilled and subsequently considered not viable for commercial power production. In the model estimates that were previously shown in this paper, it is assumed that the initial site having exploration activities and cost was the final successful site. In Figure 9, the impact of having to evaluate and drill multiple sites before a commercial site is found is shown. The costs for the 'failed' sites are included, and those costs are discounted at the higher rates. For these results, the total duration for the exploration and confirmation phases is the same as that used for a single site.

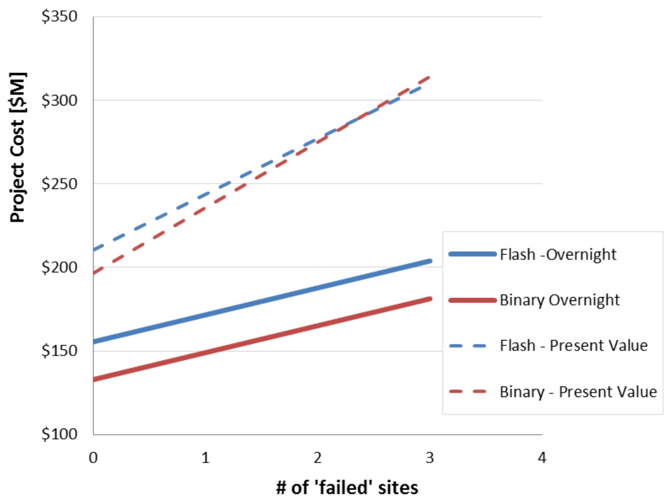

Figure 9. Effect of Number of Sites Considered on Cost

In Figure 9, both the overnight capital costs and the present value of those capital costs at startup are shown. The trends for these two costs differ for the flash and binary plant. The present value cost for the binary is increasing at a faster rate than the overnight costs. For 3 failed sites, the present value of the binary plant project is higher than that of the flash-steam project even though its overnight costs are lower. This occurred because the default values for the project phase durations were used when generating these estimates. The default period for the well field completion and plant construction for the binary plant is 2 years, while that for the flash plant is 1.5 years (both have the same duration for exploration, confirmation and permitting phases as shown in Table 1). This difference in time impacts the present value costs estimates as shown in Figure 9, and reflects the impact of the high discount rates applied to those early project activities.

5.0 SUMMARY

The GETEM estimates presented illustrate that the costs for geothermal power generation projects are site specific. Their magnitude is dependent upon both the quality of the resource used and the depth at which the resource is found. The size of the final project also impacts generation costs, in that the initial costs for the project development (exploration and confirmation) are incurred before that the ultimate level of power sales is known. As a consequence, the sales price received for the power generated must provide for sufficient revenue to recover these costs.

GETEM's ability to adequately characterize representative costs for a specific scenario is dependent upon the information provide to define that scenario. Though the model is not intended to be a definitive estimate of the performance and costs of a particular project, it can be used to provide preliminary estimates of the potential project viability.

5.0 ACKNOWLEDGEMENTS

GETEM has been developed based on contributions from a number of entities and individuals, including those from the DOE, national laboratories, contractors, academia and the international geothermal industry. The authors wish to thank all those who have made those who have those contributions. The model is currently being both maintained and modified as necessary by the Idaho National Laboratory, and again is available at the GTO web site. This work was supported by the U.S. Department of Energy, Assistant Secretary for Energy Efficiency and Renewable Energy (EERE), under DOE-NE Idaho Operations Office Contract DE AC07 05ID14517.

REFERENCES

Entingh, D. J. and Mines, G. L.: A Framework for Evaluating Research to Improve U.S. Geothermal Power Systems, Geothermal Resources Council Transactions, v. 30, (2006),741-746.

DiPippo, R.: Geothermal Power Plants, Elsevier & Butterworth-Heinemann, Waltham MA, (2012), 81-130.

Mines, G. L. and Nathwani, J.: Estimated Power Generation Costs for EGS. Thirty-Eight Workshop on Geothermal Reservoir Engineering, Stanford University, Stanford CA, (2013).