Recent Developments With GETEM (Geothermal Electricity Technology Evaluation Model)

Greg Mines

Idaho National Laboratory

Keywords

Techno-economic modeling, geothermal power generation costs

ABSTRACT

The US Department of Energy (DOE) Geothermal Technologies Office (GTO) has developed the Geothermal Electricity Technology Evaluation Model (GETEM) to provide representative estimates of the cost to generate electrical power from geothermal energy. Since its development in 2006, GETEM has gone thru different iterations to characterize specific geothermal resource and power generation scenarios, as well as to address and resolve issues that the industry has had with the estimates generated. As a result of these changes, the model became arduous to use, which limited its use by both the GTO and the public. Recent efforts have focused on making the model easier to use by incorporating model defaults that are based on the resource type (hydrothermal or EGS), temperature and depth. With these three inputs, a 'default' scenario is established and a generation cost estimated. A user can then revise up to 113 different inputs to consider other scenarios for the identified resource. This development effort included re-aligning the approach for depicting a project, and providing justification/validation for the default inputs embedded in the model. This paper summarizes the recent work done on the model and provides an overview of the work done to arrive at the defaults used to characterize a geothermal resource.

Background

The Geothermal Electricity Technology Evaluation Model (GETEM) is a tool developed to enable the GTO to comply with the Government Progress and Results Act of 1993 (GPRA) (Entinth, 2006). In this capacity, GETEM allows the GTO to assess and report annually the impact of technology improvement on the cost of generating electrical power from geothermal energy. In addition, the model also allows the GTO to identify the major contributors to these generation costs and to assess where technology improvements can have the greatest impact in lowering generation cost. This assists the GTO in aligning its research and development (R&D) portfolio to provide a beneficial return on the investment of taxpayer dollars.

Model Development

Early Development

GETEM was originally developed by a team led by Dan Entingh from Princeton Energy Resources International. The team was comprised of individuals from the industry and the national laboratories having experience or expertise in the different aspects of geothermal development. The early focus was in developing a tool for the DOE that provided representative generation costs from hydrothermal resources utilizing either flash-steam or air-cooled binary plants. Work on this version of the model ended in 2006. In 2008, the model development efforts resumed with the emphasis on characterizing the costs from EGS resources. During this period, all aspects of the model's determination of a levelized-cost-of-electricity (LCOE) were reviewed and if necessary, revised. It was during this period that the model's approach to determining the LCOE for air-cooled binary plants was revised. With this change, a macro in the model trades off the cost for more efficient power plants with either the added power produced from a given well field size, or the reduction in well field size resulting from being able to produce more power per unit mass flow.

GTO LCOE Analysis Team

In 2011, the GTO revisited the model development to improve the characterization of costs from blind or hidden hydrothermal resources. This effort was undertaken because of industry concerns that the discovery costs for these types of resource were not being captured in GETEM. Jay Nathwani (DOE-GTO) led this effort. A LCOE analysis team was assembled that conducted a series of interviews with industry subject-area experts to develop methods depict early project risk, to validate the approaches used in GETEM for all aspects of the project development, and to verify that the costs being estimated were representative. As part of this effort, revisions were made that included:

- Inclusion of a 'down-select' process where exploration activities (including drilling) needed to be conducted at multiple sites in order to 'discover' a commercially viable resource that would be developed. If this process is utilized, the costs incurred at those sites not developed were included in GETEM's LCOE determination.
- A discounted cash flow approach developed by the DOE for the Energy Efficiency and Renewable Energy (EERE) programs to estimate the LCOE was incorporated into GETEM. This approach uses the present value of all costs and revenues at the start of operation (time zero) in determining the LCOE. It allows a duration and specific discount rate to be assigned to each phase of a project. Assigning a higher discount rate to those early higher risk project activities increases their present value at startup, and hence their LCOE contribution. Discount rates applied to the other pre-operational activity costs can be lowered as more certainty regarding the commercial viability of the project is developed.
- The methods used to estimate well costs were updated to reflect the recent (2010) well costs that were provided by Sandia National Laboratory.

Previously the GTO did not have specific scenarios that were used in analyzing the impact of technology improvements on LCOE. During the work by the LCOE analysis team, a series of resource scenarios were established, and specific sets of inputs developed for each scenario. Those scenarios are shown in Table 1.

Table 1. GTO scenarios for EGS and Hydrothermal resources.

Scenario	Project Life [yr]	Temperature [°C]	Depth [km]	Flow Rate [kg/s]	Ratio Prod/Inject	Plant Type	Power Sales [MW]
EGS A	20	100	2	40	2 to 1	Binary	10
EGS B	20	150	2.5	40	2 to 1	Binary	15
EGS C	20	175	3	40	2 to 1	Binary	20
EGS D	20	250	3.5	40	2 to 1	Flash	25
EGS E	20	325	4	40	2 to 1	Flash	30
Hydro A	30	140	1.5	100	4 to 3	Binary	15
Hydro B	30	175	1.5	80	4 to 3	Flash	30
Hydro C	30	175	1.5	100	4 to 3	Binary	30
Hydro D	30	225	2.5	80	4 to 3	Flash	40
Hydro E	30	140	2.5	100	4 to 3	Binary	15

The inputs defining each of these scenarios were developed based on the industry interviews. With these scenarios defined, the GTO was able to account for the variability of the resource conditions on the LCOE, in addition to the impact of technology improvements.

Recent Modifications

At the completion of work by the LCOE analysis team, GETEM had approximately 240 inputs that were used to identify a scenario. While not all inputs were used for a particular scenario, the number of inputs still made the model onerous to use. To facilitate the use of the model, the work done by the LCOE analysis team was used to develop a set of default inputs for both hydrothermal and EGS resources, using either flash-steam or air-cooled binary power plants. These values establish a default scenario in GETEM whose LCOE can be estimated based on three inputs - a defined resource type, temperature and depth.

The sensitivity of the LCOE to GETTEM's inputs was evaluated by the LCOE analysis team. These analyses were subsequently used to identify those inputs, that if revised would have the larger impact the estimated LCOE. Those inputs (113) were selected as being values that one could change in the current version of GETEM. If changes are made to any of these inputs, GETEM estimates the LCOE for this 'Revised' scenario. If no changes are made, the 'Revised' and 'Default' scenarios produce the same generation cost. A counting logic has been incorporated that allows one to identify where there are differences between the default and revised inputs, with links to those sections of the model where the differences occur.

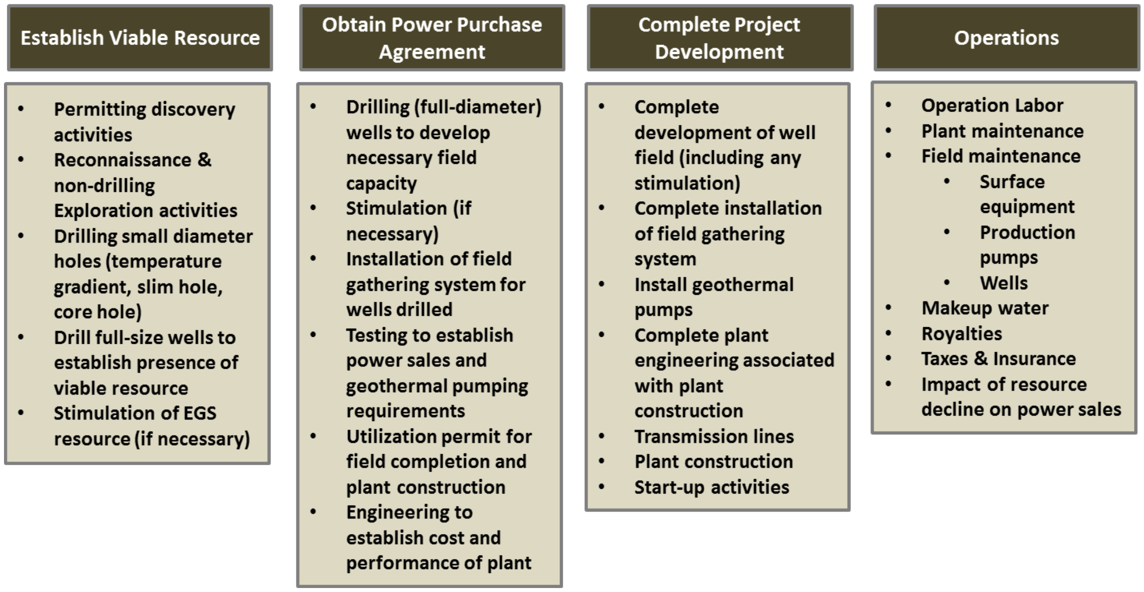

Figure 1. GETEM's depiction of project development.

The recent revisions also aligned GETEM's depiction of a project development with that in the World Bank Group's Energy Sector Managment Assistance Program (ESMAP) handbook for geothermal developments (Energy Sector Management Assistance Program (ESMAP), 2012). These revisions did not significantly alter the characterization of the activities needing to be done when developing a project, but rather altered the timing of when the activities occurred (and the costs incurred). The current depiction of a project development in GETEM is shown in Figure 1.

Other revisions that have been recently made to GETEM include:

- A schedule of major project activities is provided, along with a graph showing the timeline for incurring pre-operational capital costs.
- An option is provided to 're-finance' costs that have been incurred at the time the power purchase agreement (PPA) is obtained.
- Defaulting to using failed full-size wells drilled at the site being developed to supplement injection when evaluating hydrothermal resource scenarios.
- The model allows injection, production or both well types to be stimulated.
- When wells are stimulated, a drilling success rate and a stimulation success rate are used to determine the number of 'successful' wells.
- Failed wells for hydrothermal scenarios can be stimulated. If stimulation is unsuccessful, these wells are not used to supplement injection.

Model Validation

Defaults

Subsequent to the work done by the LCOE analysis team, efforts have been underway to validate, where possible, the inputs to the model. One of the changes made is for the default scenario to consider only those costs that are incurred at the site developed. While the inclusion of costs at all sites considered (but not necessarily developed) shows the potential impact of the early project risk, the resulting LCOE estimates are not representative of commercial projects coming on line; those are the costs that the GTO depicts in its GPRA reporting. In addition, the default LCOE estimate uses a single discount rate for all project costs and revenues that is consistent with the other EERE programs. This too reduces the impact of early project risk on the default estimate of LCOE. Though these are the defaults, GETEM still allows one to consider the impact of early project risk by including in the 'Revised' scenario the cost for undeveloped sites, as well as the use of higher discount rates for those early project activities.

One focus area for the validation of the model inputs has been on those used to characterize the performance of the reservoir. For this effort, the data reported by geothermal operators to the Nevada Division of Minerals was utilized, with a major portion of this effort accomplished by student interns working at the Idaho National Laboratory. The files used for this effort are on the National Geothermal Data System for those Nevada (NV) plants in operation prior to 2010.

Well Flow Rate

Important GETEM inputs are the flow rates for the production and injection wells. These flow rates are integral to the sizing the well field and determining the amount of pumping power required for both production and injection. Data reported by the operators in NV to the Division of Minerals was used to assess a 'typical' flow rate. Figure 2 below summarizes the reported flows from individual wells at the NV flash plants (exclusive of Steamboat Hills). Volumetric flows (gallons per month) are reported; it is assumed that the reported value is the total produced flow (steam and liquid brine), and is effectively the total flow of an 'unflashed' brine. This assumption is confirmed by comparing the total production and injection flow rates reported each month, with the difference approximating the estimated losses in the evaporative heat rejection system used in flash plants.

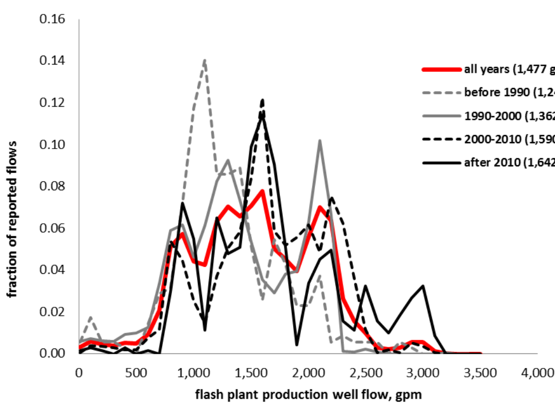

Figure 2. Distribution of production well flow rates for NV flash-steam plants.

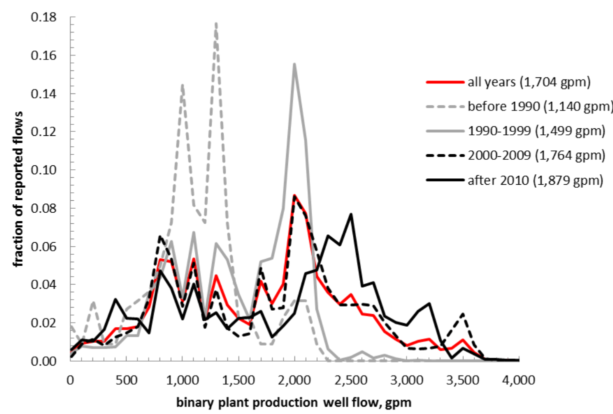

Figure 3. Distribution of production well flow rates for NV binary plants.

In this figure the frequency at which a given flow rate was reported is provided for all years having reported flow, as well as reported flows by decade (average flows are shown within parentheses in the legend). As shown there is considerable variation in the reported flow rates, though it should be noted that these flow rates are based on the total monthly flow for a well with the assumption that it produced continuously at a constant flow throughout the month. In general, flow rates have tended to increase over time. GETEM's default flow for a flash plant is 80 kg/s or approximately 1,590 gpm of liquid flow for a 250°C resource; GETEM assumes that these wells are not pumped.

A similar assessment was made for the binary plants in NV. Those production well flow rates are shown below in Figure 3.

As with the flash plants, the flows for production wells supplying binary plants have increased with time (more so than for the flash plants). Because there have been new binary facilities startups NV, the increase in flow likely reflect new production wells coming on line. It is not known if this reflects technology advancements, or the requirement that the wells be more productive for those new projects to be economically viable. GETEM's default flow for production wells supporting binary plants is 110 kg/s or approximately 1,775 gpm for a 175°C resource. While the more recent reported flows would suggest that a higher flow rate could be justified, there should be an associated increase in the Productivity

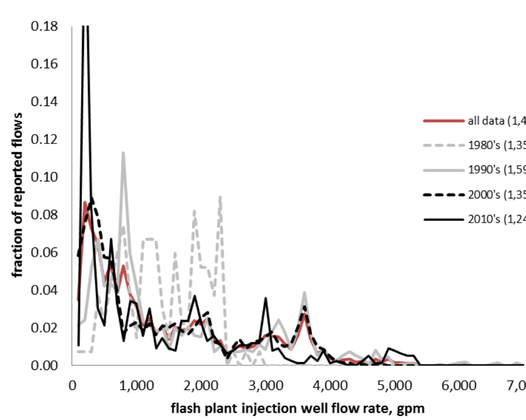

Figure 4. Injection well flow: NV flash plants.

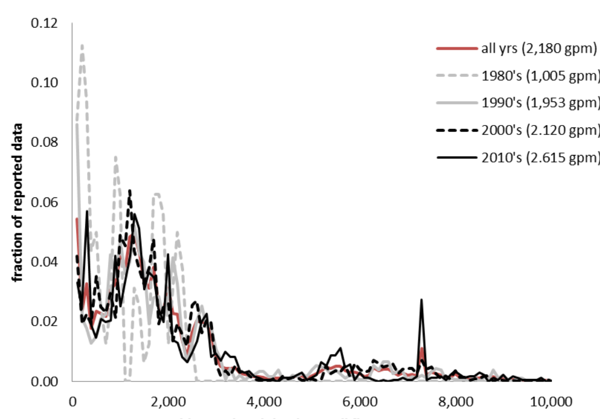

Figure 5. Injection well flow: NV binary plants.

Index (PI). This PI is an indicator of how production flow is impacted by the pressure drawdown in the reservoir; we've not been able to develop a method of determining a typical PI from the reported data. The default used (2,500 lb/hr per psi) is taken from an EPRI report prepared by CE Holt Co (CE Holt Company, 1995); this value is used for all production wells (both pumped and artesian flow). With this default PI, the flow of 110 kg/s for pumped production wells is near optimal for binary plants (in terms of the estimated LCOE).

The injection flow rates for the binary and flash plants can be assessed in a similar manner. Those flow rates are shown in the Figures 4 and 5.

There is considerable variation in flow rates for the injection wells. With both plant types a number of wells have flows that are less than 1,000 gpm. Like the production well flows, these flow rates are based on the reported total flow for the month, with the assumption that the well operated continuously throughout the month at a constant flow. It is more likely that these wells are operated periodically and/or have varying flow rates. The number of reported well flows that are less than the average flow (also within parentheses next to decade in the legend) is one of the factors that led to GETEM's default of using failed wells to supplement injection. It should also be noted that at a number of the facilities one or more injection wells take much larger flow rates (with some >10,000 gpm).

GETEM does not use an input for the injection well flow; rather it uses the ratio of the production well flow to that for a successful injection well. That flow ratio is indicative the ratio of injection to production wells, which is summarized in Figures 6 and 7 for the NV binary and flash plants. These are the counts of the number of wells that had reported production or injection flow in a given month.

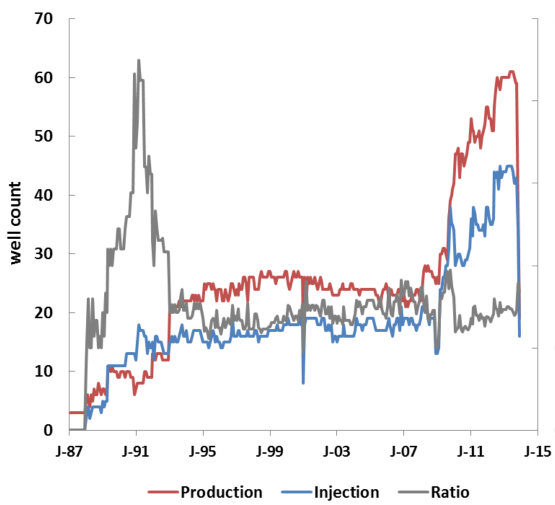

Figure 6. Well counts: NV binary plants.

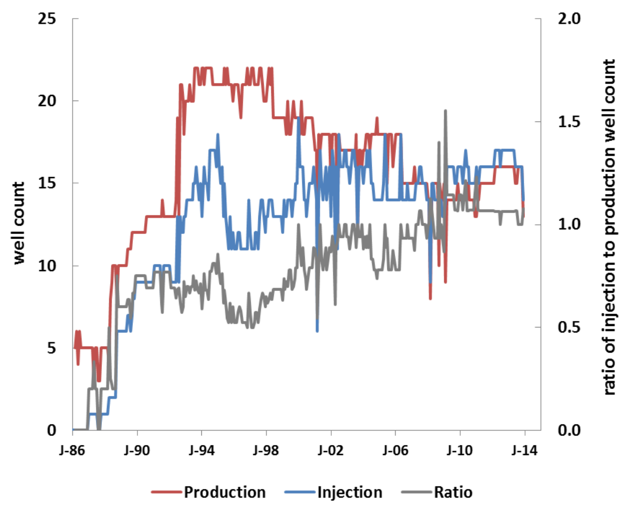

Figure 7. Well counts: NV flash plants.

Based largely on these well counts the GETEM default for the ratio of production flow to injection flow for 'successful' wells is 0.75 for both binary and the flash-steam plants.

Productivity/Injectivity Index

GETEM's default is to assume that the Productivity and Injectivity Indices are equivalent. While the Productivity Index (PI) is indicative of pressure decline in the reservoir with flow, the Injectivity Index (II) is an indicator of the effect of injection flow on the pressure buildup in the reservoir. Figure 8 below is from Allis (Allis, 2014), which was produced using data original reported by Grant (Grant, 2013). The scatter in the values shown from the New Zealand wells illustrates the variation that occurs with this parameter, which is used in GETEM to determine the level of geothermal pumping required.

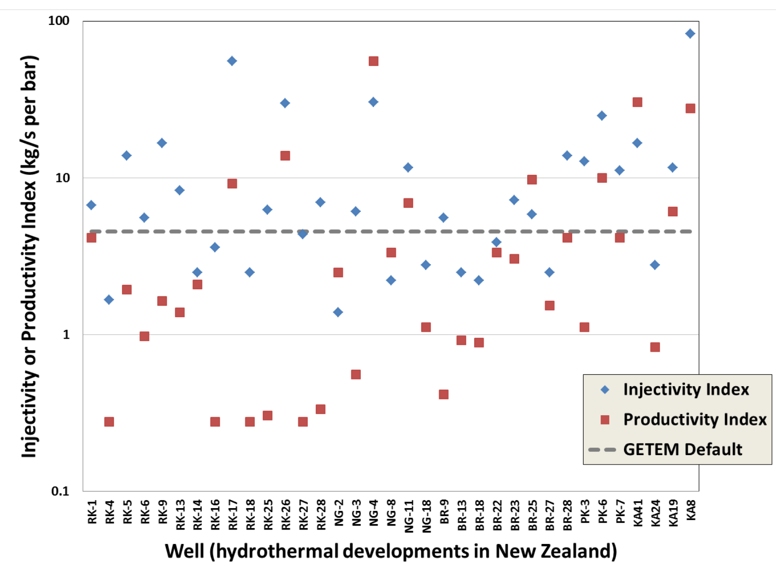

Figure 8. Productivity and injectivity indices for NZ wells.

An attempt was made to determine the Injectivity Index from the data provided by the NV binary plant operators. There was significant variation in the values determined, as indicated in Table 2; this variation reflects the difficulty in attempting to make this sort of estimate using the data available to the public. The default value used in GETEM is approximately 5.6 gpm per psi (or 2,500 lb/hr per psi), which is within the range of values found for these facilities.

Table 2. Injectivity index estimated from NV binary plants.

Facility	Injectivity Index (gpm per psi)
Binary Plant #1	2.6 to 77
Binary Plant #2	4 to 7.2
Binary Plant #3	4.9 to 575
Binary Plant #4	2.9 to 6.7
Binary Plant #5	28 to 220

Temperature Decline

The decline of the produced fluid temperatures in the NV binary plants was summarized by Hanson (Hanson, 2014). The production temperatures at these plants were used to establish an annual decline rate that is used in GETEM to determine the temperature and plant power output over the life of the project. As indicated in Figure 9 below, nearly all reported wells experience a temperature decline.

Some wells experienced an initial rapid decline in temperature; if not mitigated by changing the injection strategy, these wells were typically taken out of service. The abnormal high or low temperatures for some months were likely reporting errors. Shown in this figure is a linear curve fit that is forced to be equal to 1 at time 0. GETEM assumes that the resource temperature changes annually by some fixed percentage rate. Though this annual decline rate is not equal to the slope of this curve fit, the slope is an approximation of that decline rate.

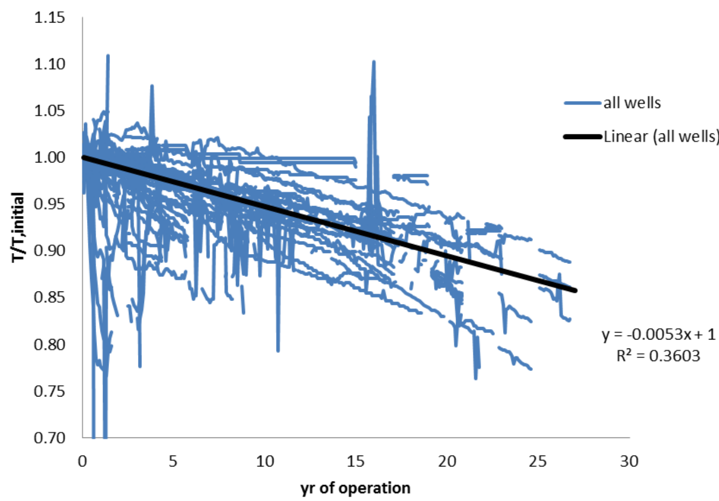

Figure 9. Production well temperature decline at NV binary plants.

For each plant reporting data, the production fluid temperature entering the plant was calculated and a temperature decline rate determined for those periods of steady operation. For this assessment, the combined decline rate for the binary plants at the Steamboat complex was similar to that of the older binary plants in NV (those in operation prior to 2005). The temperature decline at the newer facilities was higher, but that rate was influenced by the temperature decline at the Blue Mountain plant. When the Blue Mountain plant data was removed, the decline rates were slightly less than that experienced at Steamboat. The annual temperature decline rates from this analysis of the binary plants varied from 0.42% to 0.48% annually. The default used in GETEM is 0.5%, which is conservative based on the reported data from the operating plants.

Though similar data is reported for the NV flash plants, the well head temperatures reported are for the two-phase flow produced. If data were available on the steam fraction of the produced fluid, a similar analysis could be made directly from the data. In order to estimate whether the reservoir temperature was declining with time, flash plant models were used to match the reported flow and power production to a resource temperature. An example of these calculations is shown in Figure 10 for the Dixie Valley plant.

In addition to the estimated resource temperature, this figure shows the plant's specific output, or the reported power output per gpm of reported flow. The temperature estimate is that needed to match the specific output at that point in time. Through 1996, there was little change in the specific output which resulted in little change in the estimated resource temperature. Benoit's (Benoit, A Case History of the Dixie Valley Geothermal Field, 2015) (Benoit, The Long-Term Performance of Nevada Geothermal Fields Utilizing Flash Plant Technology, 2014)

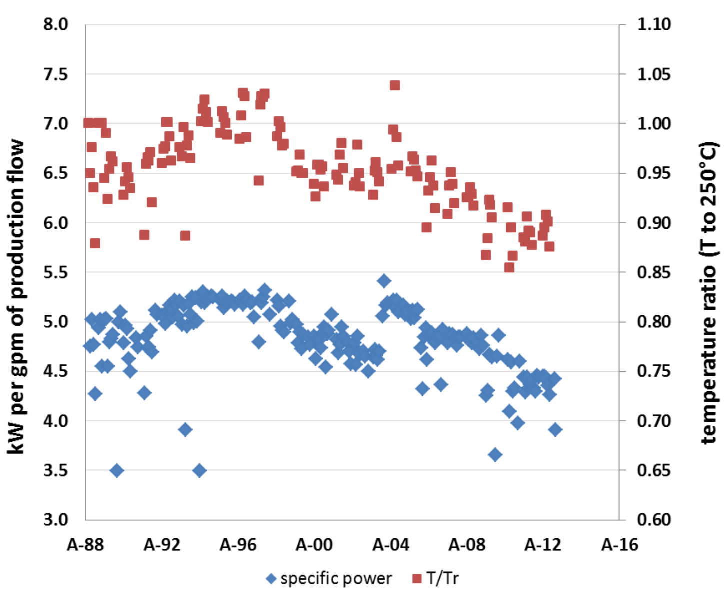

Figure 10. Estimated resource temperature for Dixie Valley plant (based on reported flow and power).

summary of the operations at Dixie Valleys indicate that through about 1997 the production and injection capacity were changing. As indicated in this figure, the specific output begins to decline in about 1996 producing a decrease in the estimated resource temperature. There appears to be a slight recovery in 2004, after which the temperature continues to decline. This apparent recovery likely reflects the turbine re-work that occurred in this time frame. Using this data, a decline rate of 0.58% was determined for the operation after 1996. If one considered the entire project life, the decline rate was approximately 0.2%. Data from Beowawe was similarly evaluated. At Beowawe, there was initially a rapid decline in the estimated temperature, followed by a longer period having a lower decline rate. During this latter period the annual decline rate of the estimated temperatures was 0.3%, while over the entire operating life, it was approximately 0.5%. The default decline rate used in GETEM for flash plants is 0.6% annually, which again appears to be a conservative value based on this limited assessment.

Effect of Declining Productivity on Power Generation

GETEM utilizes the annual temperature decline rate to depict the effect of a decline in resource productivity over time. As indicated in Figure 9, nearly all the NV facilities have experienced some decline in temperature. In GETEM this temperature decline is used to represent the decline in resource productivity, and to estimate the resulting effect on power generation over the life of a project; this power generation is the basis for the levelized cost of electricity estimate.

To determining the power generation at a point in time, the resource temperature is determined using the following relationship.

$$T_n = T_{initial}\left(1-\vartheta_{gf}\right)^n \text{, where}$$

T is the temperature of the geothermal fluid
n is point in time (in years)
is the annual decline rate

This temperature is then used to determine the available energy (or exergy) of the geothermal fluid.

$$\dot{ae} = \left(h-h_o\right) - T_o\left(s-s_o\right) \text{, where}$$

$\dot{ae}$ is the specific available energy of the geothermal fluid (per unit mass) at T_n
h is the enthalpy of the geothermal fluid at T_n
h_o is the enthalpy of the geothermal fluid at the ambient conditions
T_o is the ambient temperature
s is the entropy of the geothermal fluid at T_n
s_o is the entropy of the geothermal fluid at the ambient conditions

In GETEM, the ambient temperature is 10°C for the air-cooled binary plants, or the inputted wet bulb temperature for flash-steam plants. The power output at a point in time is the product of this available energy term, the second law conversion efficiency, the net capacity factor, and the geothermal flow rate. As the operating conditions for a plant (geothermal and ambient) deviate from the design conditions, the second law conversion efficiency invariably decreases from the design value. The effect on the second law efficiency that is used in GETEM is shown below in Figure 11.

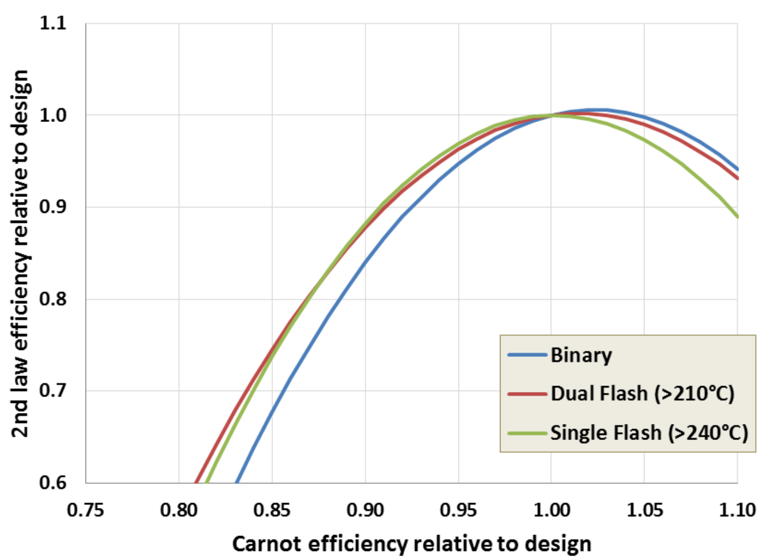

Figure 11. Effect of ‘off-design’ temperatures on 2nd law efficiency used in GETEM.

In this figure the design corresponds to a relative Carnot efficiency of 1. As the temperatures change and the Carnot efficiency changes and the second law efficiency decreases. The relationships shown are based on modeling of plants with declining resource temperatures. In GETEM, the net capacity factor term captures the effect of varying ambient conditions over a year on the plant output at the design geothermal conditions. In this figure the change in Carnot efficiency results from the change in the geothermal temperature.

To assess whether this approach estimates a decline in power generation that is representative of an operating plant, estimates made using the

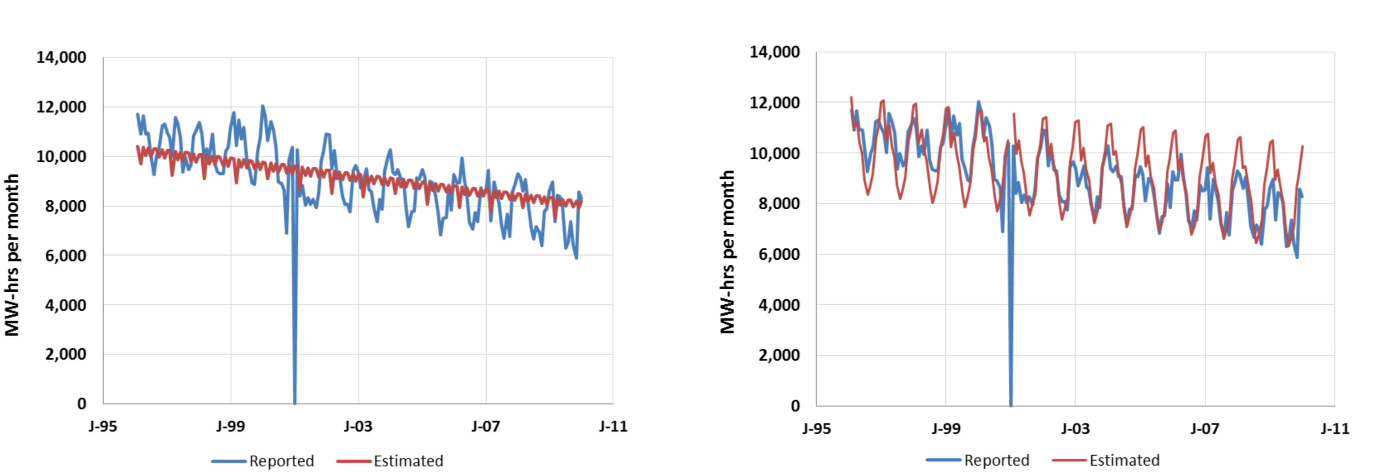

Figure 12. Comparison of reported power generation to power output estimated with GETEM methodology.

GETEM methodology were compared to data submitted by a binary operator to the Nevada Division of Minerals. Figure 12 shows the values estimated with GETEM and the reported power output.

On the left is the predicted output using the approach in GETEM where the ambient temperature is assumed to be fixed and the plant operates with a 95% net capacity factor. Over time, the reported power output decreased at a more rapid rate than estimated using the GETEM method. It is important to note that the GETEM method's estimate is based on the assumption of a fixed geothermal flow over the entire period. For this period, the total flow using the assumed fixed flow was 4.4% higher than the actual total flow reported. With the constant ambient temperature assumption (left plot), the difference in power was about 1%, with the GETEM method predicting more total power.

In right plot of Figure 12, the monthly average ambient temperature for the location was used to estimate the power production. (The varying ambient temperature affects both the available energy and the Carnot efficiency, and consequently the second law efficiency.) The estimates shown (in red) reflect the use of a net higher capacity factor of 97% (the higher capacity factor is used because the value used with the fixed ambient assumption includes the effect of the ambient temperature on power). When the power estimates include the effect of the ambient, the method used in GETEM estimates higher winter output and lower summer output. Again the estimates assume a constant flow rate, and do not include any operating constraints that might be imposed on operation. When the second law efficiency was adjusted using the average monthly ambient temperatures, the total power estimated with the GETEM method was 2.4% higher than reported (with 4.4% more flow).

The approach was also applied to a second binary plant, with the results shown below in Figure 13. At this facility, the estimated power using the GETEM method failed to match the reported power. This was due largely to the operator increasing flow rate at the facility to offset the effect of the temperature decline. Based on the reported well flows, a relationship was developed for the flow increase with time, and the relationship incorporated into the GETEM methodology. The resulting estimate of power generation is the green curve in this figure.

At this second plant, the total power generation with the GETEM method was 16.4% less, with 15% less flow. With the correction that made the flows effectively equivalent, the GETEM method's total power was approximately 1.8% less.

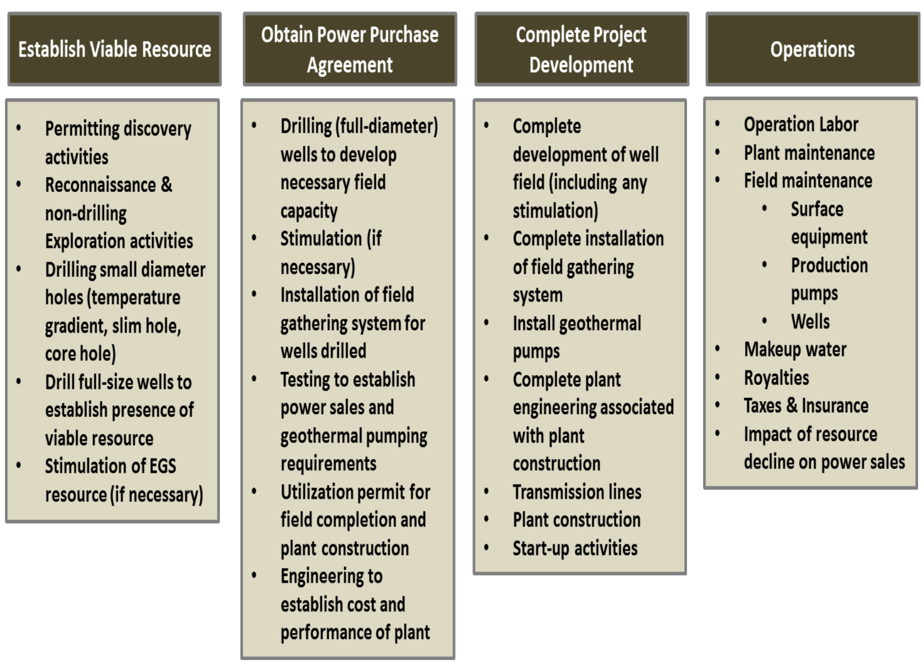

Figure 13. Comparison of GETEM methodology at second binary plant.

Both of these binary plants were evaluated using the annual decline rates determined for each, using the reported production temperatures over the intervals indicated. The comparison of estimated to actual power production indicates that the approach used in GETEM provides reasonable approximations of the effect of a temperature decline, with differences in the total power generation being similar to the differences in produced flow. The approach currently used in GETEM does not include a feature to accommodate flow changes. This is in part due to having to predict the impact of both temperature and flow changes on the second law efficiency. The review of the power production from these two binary facilities suggest the effect of varying geothermal flow on the conversion efficiency is relatively small, and that in the future GETEM could be updated to incorporate the effect in flow changes during operation, as well as perhaps the effect of changes in the ambient temperature.

Summary

The current iteration of efforts to update GETEM has concluded. For GETEM to serve its intended purpose, its estimates of cost and performance must be representative of those being encountered by industry. The current model is available to the public from the DOE GTO web site (http://energy.gov/eere/geothermal/geothermal-electricity-technology-evaluation-model), as well as from the INL web site (https://www.inl.gov/research-program/sustainable-resource-recovery/). The GTO encourages the public to utilize the model, with the user's recognition that the model is intended to provide the GTO representative costs that *could* be incurred. Feedback from users is critical to validating whether the default inputs, approaches used, and estimates developed are reasonable. As such users are encouraged to contact the GTO and provide any feedback.

It is important to note that GETEM provides a preliminary evaluation of cost and performance based on inputs provided. These estimates should not be construed as being indicative of what will occur with a specific geothermal project. Estimates for a specific project should be obtained from industry experts having the expertise required.

Acknowledgement

In developing GETEM, multiple individuals from the geothermal industry have provided invaluable input for all phases of the development of a geothermal project. Hopefully the model, as currently configured, adequately depicts that input.

The individuals who have directly contributed to developing the model include:

Dan Entingh, Princeton Energy Resources International
Gerry Nix and Chad Augustine, National Renewable Energy Laboratory
Chip Mansure and John Finger, Sandia National Laboratory
Susan Petty, Altarock/Black Mountain Technology
Mark Paster, Consultant
Ella Thodal and Steven Hanson, SRA International
Erin Camp, Sentech, Inc.
Christopher Richard, BCS, Inc.
Ma Seungwook, DOE-EERE Strategic Analysis Group
Jay Nathwani, DOE-GTO

In addition, the following Idaho National Laboratory interns have worked to utilize the data reported to the NV Division of Minerals to improve GETEM's characterization of reservoir performance.

Hillary Hanson, University of Idaho
Rachel Wood, Washington State University
Hannah Wright, Colorado State University
Dylan Glenn, Century High School, Pocatello ID

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

Allis, R. G. (2014). Economics of Developing Hot Stratigraphic Reservoirs. *38*, pp. 1047-1054. Portland OR: Geothermal Resources Council.

Benoit, D. (2015). A Case History of the Dixie Valley Geothermal Field. Geothermal Resources Council.

Benoit, D. (2014). The Long-Term Performance of Nevada Geothermal Fields Utilizing Flash Plant Technology. *38*, pp. 977-984. Portland OR: Geothermal Resources Council.

CE Holt Company. (1995). *Next Generation Geothermal Power Plants.* Palo Alto CA: Electric Power Research Institute.

Energy Sector Managment Assistance Program (ESMAP). (2012). *Geothermal Handbook: Planning and Financing Power Generation.* Washington DC: The World Bank Group.

Entinth, D. a. (2006). A Framework for Evaluating Research to Improve U.S. Geothermal Power Systems. *30*, pp. 741-746. San Diego CA: Geothermal Resources Council.

Grant, M. J. (2013). Thermal Stimulation of Geothermal Wells: A Review of Field Data. Palo Alto CA: Stanford Geothermal Workshop.

Hanson, H. G. (2014). Summary of Historical Production for Nevada Binary Facilities. *38*, pp. 1001-1005. Portland OR: Geothermal Resources Council.