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Geothermal Plant Capacity Factors

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Geothermal Plant Capacity Factors

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ABSTRACT

The capacity factors recently provided by the Energy Information Administration (EIA)[1] indicated this plant performance metric had declined for geothermal power plants since 2008. Though capacity factor is a term commonly used by geothermal stakeholders to express the ability of a plant to produce power, it is a term frequently misunderstood and in some instances incorrectly used. In this paper we discuss how this capacity factor is defined and utilized by the EIA, including discussion on the information that the EIA requests from operations in their 923 and 860 forms that are submitted both monthly and annually by geothermal operators. A discussion is also provided regarding the entities utilizing the information in the EIA reports, and how those entities can misinterpret the data being supplied by the operators. The intent of the paper is to inform the facility operators as the importance of the accuracy of the data that they provide, and the implications of not providing the correct information.

1. INTRODUCTION

The DOE Geothermal Technologies Office (GTO) utilizes the capacity factor in its analysis of the Levelized-Cost-of-Electricity (LCOE) for both current and future generation from geothermal energy. Capacity factor is a metric of a power plant's generation over time, and is used in the GTO's analyses to establish power production over time, and the associated revenue stream from the sale of that power. Low capacity factors would both be indicative of lower power generation, and result in a higher LCOE. Projects with higher LCOEs require a higher level of life-time revenues to meet capital recovery and operating costs. Project developers and potential investors utilize the capacity factor in a similar manner in assessing the economic viability of a project, often well before a power plant is constructed.

Though capacity factor is an indicator of the relative output from a plant over time, some have incorrectly used the term as an indicator of the fraction of time that a plant is providing power to the grid. Given their reliability, most geothermal plants operate a significant fraction of the time and given this definition, would have a high capacity factor. As a result, it is generally understood that high reliability and a high capacity factor are synonymous. This is an incorrect interpretation of this metric; more correctly, it represents a measure of actual output over a given time period relative to what would have been generated if the plant operated continuously at its maximum capacity over this period. While this seems to be a relatively straight forward definition, there is ambiguity with respect to the definition of output and maximum capacity.

In 2011 Bloomberg New Energy Finance (BNEF) issued a two part study to its subscribers that considered the performance of geothermal plants as indicated by their capacity factors. Their analysis indicated that the world-wide average capacity factor was ~73%, well below the 90-95% capacity factors that BNEF stated were being asserted by geothermal developers and used in project finance projections. BNEF fournd that the US average capacity factor was ~63%. This study provided some discussion as to why the capacity factors were lower than claimed by developers, including the age of a plant and field and the conversion technology. In its consideration of potential reasons why the capacity factors it was determining were substantially lower than those asserted by geothermal developers, BNEF did not appear to consider how developers were defining capacity factor. The definition used by BNEF in its study was

$$CF = \frac{Generation}{Nameplate * 8760}$$, where CF is the capacity factor.

Generation is the annual net electricity produced in MW-hr; Nameplate is expressed in MW.

For the plants in the U.S., BNEF used publically available reports and filings to establish the annual power generation and nameplate generator capacity. Similarly, the EIA collects both plant capacity and generation from geothermal operators annually.

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[1] http://www.eia.gov/todayinenergy/detail.cfm?id=14611

Given the definition used for capacity factor in the BNEF study, it is not surprising that low capacity factors were found. As pointed out in this study, the magnitude of the capacity factor found does not define project viability provided that the value is used correctly in the economic analysis. However when comparing different energy sources on their ability to provide their 'design' output, this definition unfairly depicts geothermal.

2. CAPACITY FACTORS

2.1 Definition of Plant Performance Factors

The EIA determines capacity factors for different energy sources. The figure below, taken from the EIA web site, shows recent factors that were determined using data submitted by power producers.

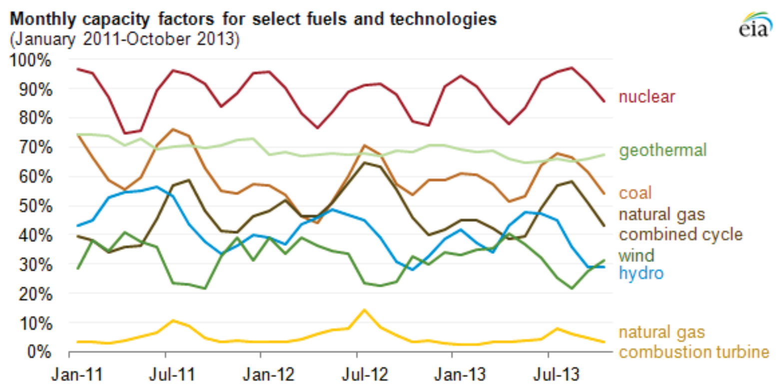

Figure 1. EIA Monthly Capacity Factors

The EIA defines capacity factor as the electricity actually produced relative to the maximum that it could have produced at continuous full power operation. In the previous figure, the EIA uses the net annual generation and the net summer capacity reported by geothermal operators to determine the geothermal capacity factor.

$$CF = \frac{Generation}{Summer\_Capacity * 8760}$$

Again, Generation is the annual net power produced, while the Summer_Capacity is the net summer capacity. The authors were made aware of how this value is determined in discussions with the EIA over the past year. It is not clear if the same methodology is used for the other energy sources as well, though it is not believed that plants using the other fuels will have a significant variation between nameplate and summer net capacities. Although similar in nature, the use of summer net capacity instead of nameplate capacity to define the maximum generation possible is why EIA capacity factors for geothermal are higher than those in the BNEF study (63%). In either case, however, it can be concluded that there is a lack of consensus as to the ideal values to use when calculating the capacity factor for geothermal plants.

The GTO is considering the adaption (for its internal use) a standard set of definitions from by the Institute of Electrical and Electronics Engineers (IEEE) as metrics expressing geothermal plant performance. These definitions are given in IEEE Standard 762 (2006). The following are some of the IEEE standard's metrics under review by the GTO

$$Availability\_Factor = \frac{Total\_Hours\_Available}{Total\_Period\_Hours}$$

$$Service\_Factor = \frac{Total\_Hours\_In-Sevice}{Total\_Period\_Hours}$$

A plant's availability factor is not dependent upon the plant actually operating, but rather that it could be operated if called upon to do so. The plant's service factor is indicative of the fraction of time that plant is operating, but is not indicative of the level of power provided over the period duration.

Most important to this discussion, the IEEE defines multiple indicators of plant performance relative to its maximum capacity. The GTO is considering the use of the IEEE definition of the net capacity factor, as well as its gross capacity factor to characterize plant performance relative to what would be expected. The IEEE defines there metrics as

$$Net\_CF = \frac{Net\_Generation}{Maximum\_Net\_Generation} \text{ for time period}$$

$$Gross\_CF = \frac{Gross\_Generation}{Maximum\_Gross\_Generation} \text{ for time period}$$

The above characterization of the net capacity factor is incorporated into GETEM (Geothermal Electricity Technology Evaluation Model) to characterize the plant's theoretical performance at design resource conditions. This capacity factor is then degraded over time to reflect the impact of a decline in the produced fluid temperature.

2.2 Impact of Definition on Capacity Factors

The capacity factor definition used by BNEF would provide a representative depiction of how a plant's performance meets expectations if there is no power consumption in the operation of the plant, i.e., wind or PV solar facilities. It would also be representative of plants using high temperature energy sources (nuclear and those burning fossil fuels) where the plant's parasitic power needs are relatively small compared to the generator output. Geothermal plants, especially those using the binary cycle technology, consume a larger portion of the generator output. As a consequence , the power to the grid will be proportionally lower, even if the plant operates continuously at the net generation it was designed to provide. This is a geothermal plant's design capacity and should not be confused with the nameplate capacity commonly used in these types of analysis. The design capacity is also used as the basis for the developer's power purchase agreement (PPA). Consider the following scenarios for two postulated geothermal plants.

Table 1. Geothermal Plant Scenarios

Parameter	Air-Cooled Binary	Flash Steam
Resource Temperature	165°C	250°C
# Production Wells	4	4
Production Well Flow	80 kg/s	75 kg/s
Production Pump Depth	200 m	NA
Injection Pump Head	100 m	100 m
Pump Efficiency	70%	70%
Geothermal Pumping Power	1.3 MW	0.4 MW
Generator Output	17.7 MW	37.8 MW
In-plant Parasitic Load	2.3 MW	1.8 MW
Net Power to Grid	14.1 MW	35.6 MW
Fraction of Time Operating	100%	100%
Annual Generation(@Design)	123,516 MWh	311,856 MWh
Maximum Annual Capacity	155,052 MWh	331,128 MWh
Capacity Factor	79.7%	94.2%

The capacity factors shown here are based upon the plant operating continuously at its design output over the entire period (1 year). If the plant had operated 95% of time, the capacity factor would be 5% lower, ie., 75.7% for binary and 89.5% for flash.

Relative to conventional fossil plants, liquid-dominated geothermal fluids are a relatively low temperature source of energy. As a consequence the output of these plants is more sensitive to changes in the temperature of the heat sink to which they reject heat, especially those rejecting heat sensibly to the ambient environment (air-cooled condensers). The sensitivity of the output of these plants to the sink, or ambient temperature is illustrated by examining the corresponding changes in the geothermal fluid's available energy or exergy. Available energy, or exergy, represents the ideal power that could be produced by a conversion system operating between the source (geothermal fluid) and sink (ambient) temperatures. In Figure 2, both the exergy value and the relative change in the exergy are shown as a function of the sink temperature. The relative change in exergy is given relative to a 12°C (53.6°F) design temperature for the heat sink. This design temperature

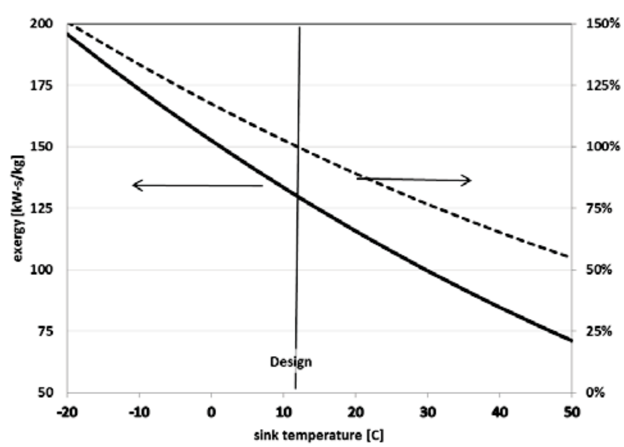

Figure 2. Effect of Sink Temperature on Ideal Power for Plant with 165°C Resource

represents the mean air temperature in the US; it is common practice to design air-cooled plants at either the mean or average temperature for the plant location.

If the conversion rate (2nd law efficiency) of available energy or exergy to power is constant, the net power generated will mirror the changes shown in this figure. When the sink temperature is less than design, the plant as the potential to produce more power. If the developer designs the plant to take advantage of this potential, the plant's generator will have a higher nameplate capacity. Figure 3 shows the estimated annual net generation profiles for the air-cooled binary plant scenario, using the 2010 air temperatures from Fallon NV (information downloaded from MesoWest web site[2]).

The profiles shown in Figure 3 are based on estimates of hourly power output throughout the year both with no limit placed on the generator output and with the maximum generator output limited to its output at the design conditions (in this case a design air temperature of ~11.1°C). Also shown in the figure is the estimated output from both generator scenarios for a 15°C decline in resource temperature that occurs over some indeterminate period. The calculations are based the estimated impact of changes in both the ambient air and resources temperature on the 2nd law efficiency, which is then applied to the exergy calculated to determine the hourly net power generation. These estimates assume that the geothermal flow rate is not increased and that the availability/service factor is 100%. Table 2 summarizes the performance for these two design options and the effect of the geothermal temperature decline. The capacity factors shown in this table that are based on the maximum gross generator output (assumed to be 'nameplate') are representative of those used in the BNEF study, with the exception that the values shown above to not reflect outages that do occur. If these outages, scheduled or unscheduled, totaled one week the capacity factors would be ~2% lower than shown. The capacity factors that are based on the maximum net generation, as determined by the design net output, are more indicative of how well the plant's output meets expectations.

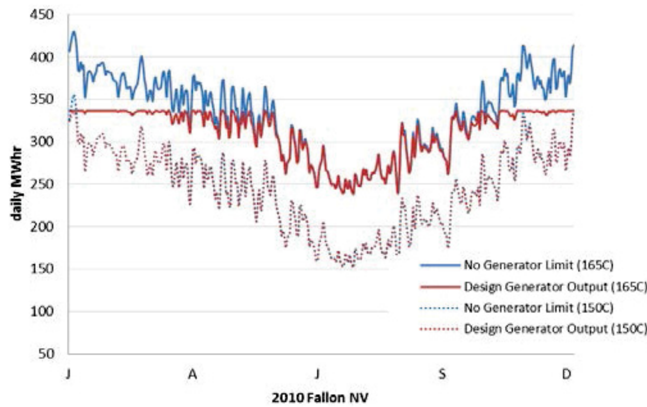

Figure 3. Estimated Annual Generation Profile for Air-Cooled Binary Plant (Design: 165°C Resource)

Table 2. Effect of Resource Decline and Limitations on Generator Output and Effect

	No Limit on Generator	Design Generator Output	No Limit on Generator	Design Generator Output
Geofluid Temperature	165C	165C	150C	150C
Service Factor Assumed	100%	100%	100%	100%
Estimated Annual Net Generation	120,718 MW	113,654 MW	88,978 MW	88,886 MW
Maximum Generator Output (gross)	21.9 MW	17.7 MW	21.9 MW	17.7 MW
Annual Maximum Gross Generation (based on max generator output)	191,707 MW-hr	154,737 MW-hr	191,707 MW-hr	154,737 MW-hr
Capacity Factor Based on Annual Maximum Gross Generation	63.0%	73.4%	46.4%	57.4%
Design Net Output	14 MW	14 MW	14 MW	14 MW
Annual Maximum Net Generation (based on design output)	122,772 MW-hr	122,772 MW-hr	122,772 MW-hr	122,772 MW-hr
Capacity Factor Based on Annual Maximum Net Generation	98.3%	92.6%	72.5%%	72.4%

Binary plant generators may be air-cooled, making it possible that a generator designed for a nameplate capacity of 17.7 MW at the mean ambient temperature may be capable of operating at higher power outputs without damage at colder ambient temperatures. This possibility was not considered in the results shown in this table.

[2] http://mesowest.utah.edu/

The BNEF study indicates that one reason for capacity factors being lower than claimed by developers is the decline in resource productivity (temperature and/or flow rate) over time. A decline in resource temperature adversely impacts both the geothermal fluid's exergy and the conversion of that exergy to power (2nd law efficiency). As shown in Table 2, the combined effect lowered the net generation from the postulated plant by 22 to 27%. Analysis of the historical production data from the NV geothermal facilities by Hanson (2014) showed that most, if not all, of the binary geothermal plants experienced a decline in the production fluid temperature over time. Hanson's analysis indicated that in response to the decreasing temperature and output, operators typically increased the production flow rate. Consequently those plants experiencing a declining resource temperature do not necessarily have the decrease in annual net generation that would otherwise occur. The analysis given in this paper for the postulated plant scenario is indicative of what would be expected where a resource cannot be further developed beyond the production initially provided.

The scenario presented here is for a lower temperature resource and air-cooling. The power generation from plants using higher temperature resources, as well as those with water cooling (evaporative heat rejection) will also be impacted by decreasing source and varying sink temperatures. The impact on output when using higher temperature resources is lower because these fluids have a higher initial exergy, or available energy. Though water-cooled plants are also sensitive to changes in the sink temperature, they reject heat to the ambient wet-bulb temperature. As a consequence these plants do not experience the level of variation in power output throughout the year as an air-cooled plant.

3. EIA PERFORMANCE METRICS

3.1 Information Reported to EIA

The EIA annually conducts surveys where geothermal operators report both capacity (form 860) and generation (form 923). These reports are mandatory[3] for plants having a total generator name plate capacity of 1 MW or greater.

In the generation survey (form 923) geothermal operators report net generation (MWhr) for each month of the year. EIA defines gross generation as the total electrical energy produced by the generating units as measured at the generating terminal. Net generation is the gross generation minus the parasitic station load. The station load is the electricity that is used to operate and maintain the electrical power plant portion of a facility. Non-utility plants (unregulated plants) also report gross generation and disposition of the electricity produced. If power is purchased by a facility, that incoming power is reported – an example might be the purchase of power for geothermal production or injection pumps. For these unregulated plants, if generated power is used for energy storage or for an industrial application within the facility, those power requirements are not included in the station use, and are reported as a direct use. Most geothermal plants are listed as non-utility generators in the EIA's annual summaries of the data collected.

In the survey of plant capacity (form 860), geothermal operators report the name plate and net capacities of each plant generator. For each generator, net capacity is reported as both summer and winter. The instructions for this form do not explicitly define either net summer or net winter capacity; however they do refer to the online EIA Glossary[4], where the net summer capacity is defined as

> '*the maximum output that the generating equipment can supply to system load as demonstrated in a multi-hour test at the time of summer peak demand (June 1st thru September 30th). This output reflects the reduction in capacity due to electricity use for station service.*'

The definition of net winter capacity is identical with the exception that it be established with a test be conducted during peak winter demand (December 1st thru February 28th). Because net capacity accounts for the station usage or load, it is unlikely that the net generator capacity (especially summer) would exceed the nameplate capacity. It is particularly unlikely for binary plants where the authors believe the production and injection pumping power should be included in this parasitic load.

The IEEE explanation of the gross and net maximum generation used in its capacity factor definitions indicate these values are established with formal testing to quantify each (the IEEE does not utilize the installed nameplate capacity as the maximum gross capacity). The authors have yet to identify the requirements to satisfy the IEEE's formal testing, or to establish the capacities reported to the EIA.

Figure 4 shows a week's generation profile in both the summer and winter for the postulated air-cooled binary plant using the 165°C resource case. The design generator output was 17.66 MW. If the generator was limited to that maximum output, the winter net capacity would be the design output (14.02 MW), while the net summer would be ~11.4 MW. If

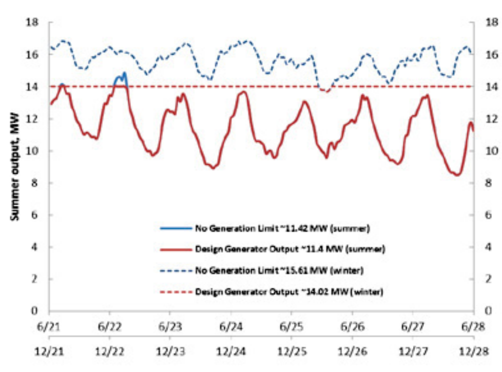

Figure 4. Summer and Winter Power Generation Profile

[3] Federal Energy Administration Act of 1974 (Public Law 93-275)

[4] http://www.eia.gov/tools/glossary/

the generator output was not constrained by the design condition, then the net capacities would be ~15.6 MW in the winter and 11.42 MW in the summer.

These capacities shown here are based on one week of operation. If these metrics were based on 24 hours of operation, the values could be higher or lower depending upon the day selected. If conducted over a period of a few hours, the values would depend upon the time of day the testing was performed. Regardless of the value used, the output from the plant would not have changed even though the capacity factor would have.

Geothermal operators also report to the EIA when generators are retired or out of service. When the units are retired, the total facility capacity is reduced by the reported capacity for each generator retired. When units are out of service during the year, the EIA reduces the maximum possible annual generation capacity to reflect those units out of service.

3.2 Assessment of Data Reported to EIA

The following table summarizes the data reported to the EIA[5] over the 5 year period from 2008 through 2012. The information reported by the operators indicates most of the increase in capacity has come from new installed binary capacity. The increase in the binary net generation over this period is slightly larger than the total increase in net generation. Some decline in the total generation from flash steam plants occurred, even though the flash capacities increased over this interval; note most of the change in flash plant capacity and generation occurred in 2012. Note the capacity given reflect the values reported for operating generators in a given year. In reviewing the EIA data we've found that in some instances generators are reported as being retired several years previously, though in the intermediate period that generator is reported as being operational. We've no way to determine which of the reported data is correct, so in this table and the subsequent figures, the operating generator capacity as reported is used,

Table 3. Reported Geothermal Capacity and Generation Data, 2008-2012

	2012	2011	2010	2009	2008
Nameplate Capacity (operating generators)					
Geothermal (MW)	3,549.4	3,380.2	3,378.2	3,301.1	3,123.4
Geysers (MW)	1,724.8	1,779.8	1,779.8	1,779.8	1,779.8
Flash Steam (MW)	1,068.6	972.8	969.2	929.6	929.6
Binary (MW))	756.0	627.6	629.2	591.7	414.0
Net Summer Capacity (operating generators)					
Geothermal (MW)	2,494.8	2,342.0	2,337.4	2,314.7	2,161.6
Geysers (MW)	1,053.0	1,086.9	1,086.9	1,086.9	1,086.9
Flash Steam (MW)	882.0	791.3	790.0	790.0	790.0
Binary (MW)	559.8	463.8	460.5	437.8	284.7
Annual Net Generation					
Geothermal (MW-hr)	15,544,648	15,316,068	15,219,213	15,008,658	14,797,441
Geysers (MW-hr)	7,061,711	6,927,510	6,892,158	6,940,723	7,062,118
Flash Steam (MW-hr)	5,939,193	5,961,939	5,999,933	6,176,495	5,997,448
Binary (MW-hr)	2,543,744	2,426,619	2,327,122	1,891,440	1,737,875

From this data one can determine the 'fleet' capacity factors. Those capacity factors are shown in Figure 5. They show the capacity factor trend for the entire geothermal fleet is decreasing over this interval, with the decrease being largely attributable to decreasing capacity factors for both the flash and the binary facilities. Note that the decrease in the binary (and geothermal) capacity factor in 2009 is the likely the result of a number on new binary facilities coming on line and their not generating over the entire year. We've made no attempt in this data to correct for this; the EIA does when it reports geothermal capacity factors.

The decline in the overall geothermal capacity could be attributed to the new generation from binary plants if the capacity factor shown were based on the nameplate capacity (as previously discussed, the inherently higher parasitic plant load for binary plants result in lower capacity factors defined using the nameplate for maximum generation). This is not the case in this figure, where the operator's reported summer net capacity is used; this capacity should account for the plant parasitic load as well as the effect of higher ambient temperatures on output. Using this net summer capacity, one would have expected a capacity factor approaching unit, unless plant

[5] http://www.eia.gov/electricity/data/eia923/ and http://www.eia.gov/electricity/data/eia860/

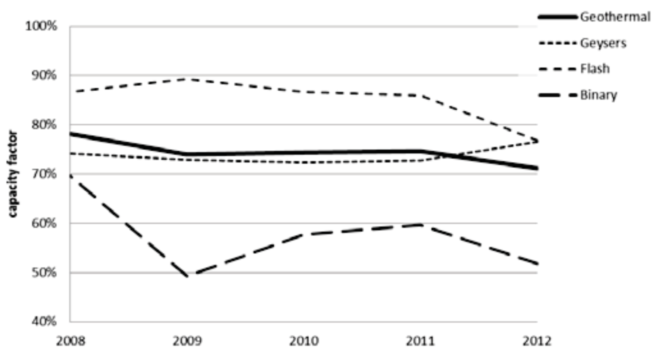

Figure 6. Geothermal Capacity Factors Based on Reported Net Summer Capacity

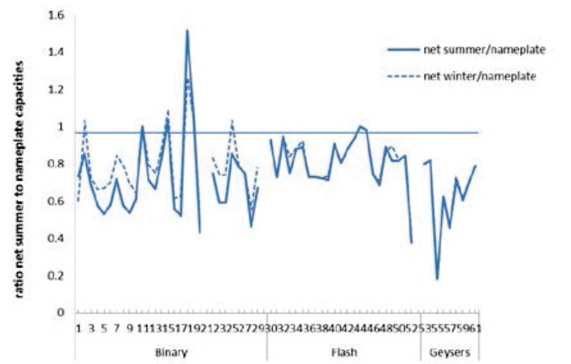

Figure 5. Capacities Reported to EIA in 2012

output is being curtailed either due to the inability to sell all the power that could be produced, or due to the adequacy of the resource to support the installed capacity.

If plant output is not being curtailed then the lower capacity factors could result from either the data being reported, or errors introduced in consolidating the reported data into the EIA summary files. If there are issues with the reported data, we suspect they most likely arise from reported capacities. One potential issue is in the reporting of the net summer capacity. Figure 6 shows the ratio of the net summer to nameplate capacities reported to the EIA in 2012. Per the prior discussion on the postulated air-cooled binary plant performance, it is unlikely that the net summer capacity of a binary plant would equal or exceed the nameplate capacity, yet there are some plants that report summer capacities are equal to or exceed the nameplate capacity.

There is an issue with the retirement of generators; specifically when that retirement is reflected in the EIA summaries of reported capacity. It is unclear if this is related to confusion on the names the operator assigns to generators when completing the 860 survey, operators neglecting to report the retirement, or the EIA files not being updated to reflect the retirement.

In one instance that we are aware of, capacities are reported for 6 different generators at a facility having 3 generators. We are not sure if this is related to a change in ownership, with new names assigned to the existing generators, or if is an error that has gone uncorrected.

In addition to looking at the 'fleet' performance, the EIA data can also be used to look at the performance of individual facilities. In Figure 7 the monthly generation from 2008 through 2012 are shown for one flash plant and 4 binary plants. The flash plant and one of the binary plants (# 4) began operation prior to 2000. The output from these two plants more closely approach their reported net summer capacity than the three binary plants examples that began operation after 2000. We can offer no explanation for this other than the operator is reporting summer capacities that more closely approach actual performance. The performance of the newest plant (Binary #1) improved over its first year of operation. This is expected as any initial issues with the operation of the plant and well field are resolved. The generation of the other two binary plants are less than net summer capacity. This could be an issue with the reported capacity or to curtailment of the plant, possibly an issue with the productivity of the resource.

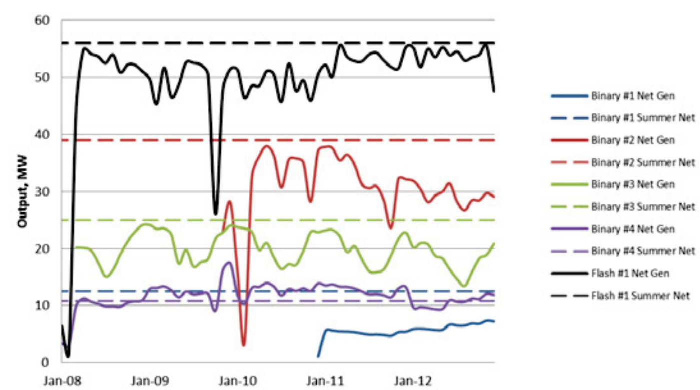

Figure 7. Reported Generation and Net Summer Capacity for Selected Geothermal Plants; 2008-2012

4.0 SUMMARY

Though capacity factor is a term frequently used by geothermal stakeholders, it is not a term used consistently, and in some instances, is not used correctly at all. Though geothermal plants have demonstrated reliability, the definitions of capacity factor used by some stakeholders do not reflect the high levels of availability achieved by geothermal plants. While it is true the power produced from geothermal plants (in particular those using lower temperature resources) is sensitive to changes in both ambient temperatures and resource productivity, geothermal developers design these plants and manage the resources with these impacts in mind. They recognize that plants can consume a significant portion of the power that is generated in order to put power on the grid, and include these parasitic loads in their evaluation of a project's economic viability. What is of importance to developers and operators is that the plant generates sufficient power to satisfy the terms of their PPA.

For those working to develop new projects, and for geothermal stakeholders aside from those operating facilities, the magnitude of capacity factors that are reported or can be derived from public information (EIA) has importance, and should reflect the purported reliability of geothermal plants. Data provided by the operators to the EIA suggests geothermal has lower capacity factors than many have thought, including the authors. It is not clear if these capacity factors truly depict geothermal plant performance, or if they are indicative of reporting errors or misunderstanding as to what information is being requested. The intent of this paper is to solicit discussion from the geothermal stakeholder on plant performance metrics, including capacity factors, as well as on the data provided to the EIA. The hope is that these discussions lead to clarity and consistency in the terms and data provided.

5.0 ACKNOWLEDGMENTS

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