

Baseline Geothermal Power Capacity in the USA and California

Will Pettitt¹, Brian Schmidt¹ and Jody Robins²

¹**Geothermal Resources Council (GRC), wpettitt@mygeoenergy.org**

²**National Renewable Energy Laboratory (NREL), Jody.Robins@nrel.gov**

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ABSTRACT

As states in the USA adopt more ambitious targets within their Renewable Portfolio Standard (RPS) they need to create an energy mix that provides the power grid with resiliency, reliability and stability. An RPS is now adopted in 29 states, with California, for example, targeting 60% renewable by 2030 and 100% “clean” by 2045. The renewable-energy demand cannot be fulfilled by intermittent sources alone and baseload power will be required. Geothermal power provides flexible baseload with capacity factors that are higher than any other power resource except nuclear. Additionally, geothermal delivers load balancing and ancillary services that help maintain the stability of the transmission grid. The demand for geothermal energy will only increase.

In April 2019, the California Public Utilities Commission (CPUC) gave the geothermal industry a target to supply 2,900 MW of net power into the grid by 2030. What does this target mean in terms of today’s power generation and how do we achieve that target? In order to implement a strategy, we must first understand the baseline power capacity onto which the industry must build. This paper uses publicly available data from the US Energy Information Administration (EIA) to collect and assess metrics that can be used to help form strategies for industry growth. An accompanying collaboration between the National Renewable Energy Laboratory (NREL) and GRC will build on these results with a report published at the end of 2020.

The Nameplate Capacity for the USA is 3,806 MW, which has grown only 2% since 2012. Two important performance ratios are defined – Net Capacity Factor and Supply Ratio – that link the power supplied to the grid with nameplate capacity. Using these learnings, it is shown that the total installed capacity in California needs to be 5,750 MW in 2030 to achieve the CPUC target.

An industry-led strategic task force is proposed with the goal of planning sufficient geothermal installation over the next 10 years to meet this demand.

1. Introduction

In the USA, California is leading the way for the geothermal industry. With substantial resources at its fingertips, the state is targeting a transition to 100% renewable and emission-free power by 2045. Geothermal energy will be a major piece of the transition if the industry can successfully overcome hurdles to resource development and build out sufficient power capacity. The value of geothermal power to the electricity grid is well established with various key attributes summarized by Matek and Schmidt (2016). The people of California are demanding an energy future based on low carbon fuels but without nuclear power. The evolution of the geothermal power market in California is therefore important to the worldwide geothermal community as it highlights geothermal power's critical role in transitioning to renewable energy.

The two professional and trade associations, Geothermal Energy Association (GEA) and Geothermal Resources Council (GRC), consolidated in the summer of 2018. The new GRC took over many of the functions that the GEA once pursued. A GRC Policy Committee (PC) was created to advocate for geothermal energy with state and federal governments and international organizations. Until 2016, the GEA provided a series of popular "State of the Industry" reports that included both national and international generation and resource metrics (the latest report was Matek, 2016). In an effort to report latest generation metrics, the GRC has joined with the National Renewable Energy Laboratory (NREL) to conduct collaborative new research that will lead to an updated report being published in early 2021.

In California, the California Public Utilities Commission (CPUC) is undergoing a multi-year process of modeling the future power generation mix through 2030. Its Integrated Resource Plan (IRP) (CPUC, 2019) published in April 2019 was an important decision for the geothermal industry. The goal of the IRP is to provide a guide for independent utilities within their procurement plans so that the State's Renewable Portfolio Standard (RPS), Green-House Gas (GHG) and Resource Adequacy (RA) goals can be achieved. The decision gives the geothermal industry a target for supplying 2,900 MW of net power into the grid by 2030.

This paper aims to provide a better understanding of what the geothermal industry in California needs to achieve to accomplish this goal. To begin any new strategy for building out geothermal power, it is first important that we clearly understand the baseline metrics of today's generating capacity so that accurate objectives can be formulated. This paper uses publicly available data from the EIA to form a baseline for future growth and to help form a strategy for geothermal penetration in power markets.

2. BASELINE FOR THE USA

2.1 Installed Nameplate Capacity

The total installed geothermal nameplate capacity for the world at the end of 2019 was approximately 15,406 MW (Richter, 2020), with the USA at approximately 3,676 MW, Indonesia at 2,133 MW, the Philippines at 1,918 MW and Turkey at 1,526 MW. The term “nameplate capacity” must be understood to appreciate how the future installed capacity of a geographical area like the USA or California relates to targets for future energy (or net generation) supplied to a given power grid.

Figure 1(a) presents the generation capacity for the USA based on data from in the “EIA 2018 Electric Power Annual” (EIA, 2019). The EIA definition of terms is considered here:

- Installed generator “Nameplate Capacity”: The maximum theoretical output in megawatts (MW) of a generator as reported to the EIA database by the manufacturer/operator of that generator.
- “Net Summer Capacity”: The maximum output in MW that generating equipment can supply to system load, as demonstrated by a multi-hour test, at the time of peak summer demand (May 1 through October 31). This output reflects a reduction in capacity due to electricity use for station service or auxiliaries.
- “Net Winter Capacity”: Similar to Net Summer Capacity but at the time of peak winter demand (November 1 through April 30).
- “Net Generation”: The amount of gross generation (the total amount of electric energy produced by generating units in megawatt-hours (MWh)) less the electrical energy consumed at the generating station for station service or auxiliaries.

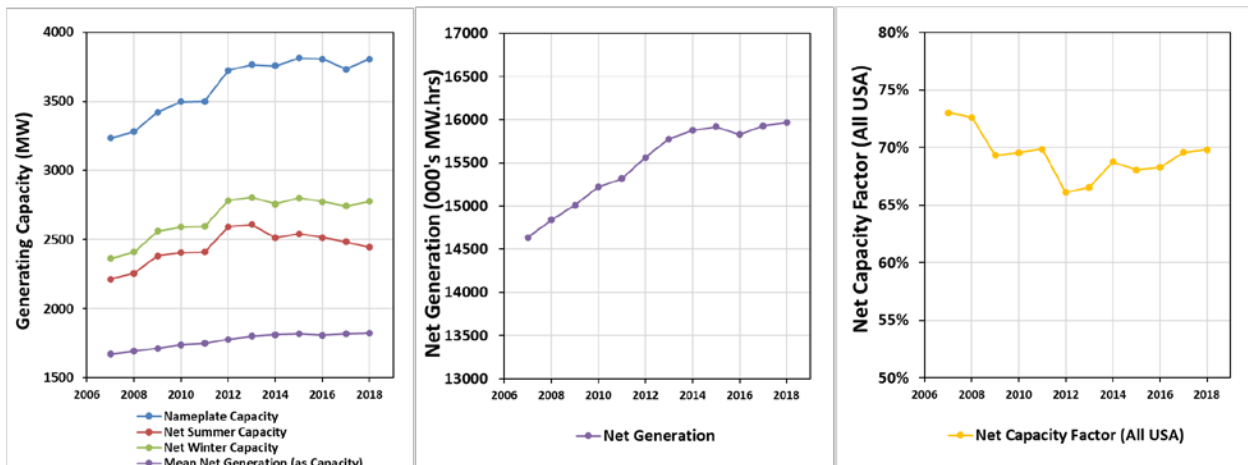


Figure 1: Generation metrics for geothermal power in the USA compiled from data published by the EIA in EIA 2019. Note that the most recently reported annual data is from 2018. 2019 data is expected to be published in the Autumn of 2020.

In other words, *Nameplate Capacity* is a theoretical estimate of power provided by an operator considering the geothermal resource and installed equipment, *Net Summer and Winter Capacities* are generating power capacity provided under test conditions, and *Net Generation* is the actual energy provided to the grid.

The Nameplate Capacity for the USA according to EIA data for end 2018 is 3,806 MW. As can be seen from Figure 1(a), this is slightly lower than the peak Nameplate Capacity of 3,812 MW attained in 2015, presumably due to net decommissioning of some geothermal generating megawatts from the total USA system (i.e. decommissioning of geothermal power in the USA in the past few years has been marginally greater than commissioning of new power). The Nameplate Capacity generally aligns with estimates from Matek (2016) and Richter (2020) published across different years.

Considering the EIA data available beginning in 2007, as described in Figure 1(a), it's clear that total geothermal Nameplate Capacity has not meaningfully advanced in the USA since 2012 when there was 3,724 MW. This equates to a 2.2% increase over the six years between 2012 and 2018 compared with a 15% increase over the five years between 2007 and 2012. These numbers do illustrate one success: decommissioning of old power plants over the whole period has not outstripped commissioning of new ones.

2.2 Nameplate Capacity versus Reported Capacity Tests

Arguably the Net Summer Capacity and Net Winter Capacity could be considered more reflective of the installed generating capacity for a particular region as these metrics are based on test data yielded by the power generators. The capacity values for the whole of the USA, shown in Figure 1(a), demonstrate the well-known difference between the efficiency of geothermal plants due to the change in ambient outside air temperatures and thus appear meaningful. In winter months, the greater difference between air temperature and produced steam temperature at a given geothermal plant results in a greater power output. Both capacity metrics also illustrate the stagnation in net geothermal power installation as both metrics peaked in 2013 and have declined since. A more convenient assessment of these two capacities is to take the mean of the two measurements each year, which we will call Net Seasonal Test Capacity. The maximum Net Seasonal Test Capacity for these two metrics was 2,706 MW in 2013 compared with 2,611 MW recorded in 2018.

There is a significant difference (~1,200 MW) between the Nameplate Capacity in 2018 (3,806 MW) versus the measured Net Seasonal Test Capacity (2,611 MW). Thus, there is a 30% difference between what can be practically output from generators versus what the theoretical output is considered at installation. Assuming the EIA database is complete and accurate, the 30% reduction in power output must consist of: a) electrical consumption and inefficiencies at the generating power plant; b) reduction in operating capacity at older plants and geothermal fields meaning that the original theoretical Nameplate Capacity is no longer possible; c) decommissioning of equipment and resources not considered in the reported Nameplate Capacity. Considering that some of the geothermal plants in the USA are many decades old then some of these effects are probably due to a mature industry and allude to the fact that more work is required to accurately quantify the state of the industry in the USA.

2.3 Reported Capacity Tests versus Actual Output

Considering the Net Summer and Winter Capacities are short term tests then how do they compare with what is actually output to the grid over the long term? The EIA data recorded for Net Generation from all USA geothermal power plants is provided in Figure 1(b) for the same time period. The annual Net Generation generally increases through to 2018 with a peak at 15,967 GWh, although the rate of annual increase slows since 2012 and describes a decrease from 2015 to 2016. An increase in Net Generation of 2.3% tracks the Nameplate Capacity increase over the same period of 2.2%.

Net Generation can be converted to a “Mean Net Generation” capacity defined here (shown in Figure 1(a)) assuming the entirety of the annual generation is equally spread throughout the year, 24 hours per day. The Mean Net Generation for the whole of the USA in 2018 is 1,823 MW, or 48% of Nameplate Capacity. This ratio of Mean Net Generation to Nameplate Capacity we will define as the “Supply Ratio” to distinguish it from the “capacity factor” terminology.

Instead, a “Net Capacity Factor” can be defined as the ratio of the Mean Net Generation to the Net Seasonal Test Capacity defined in the previous section. We use the measured Net Summer Capacity and Net Winter Capacity rather than the Nameplate Capacity as it suffers from the highly uncertain, and somewhat arbitrary, measures of capacity described earlier. The Net Capacity Factor is a more reliable indicator of market performance than the Supply Ratio. The Net Capacity Factor in Figure 1(c) shows that the geothermal industry in the USA has generally increased in efficiency of power supplied to the grid, from a factor of about 66% in 2012 to about 70% in 2018. Since the Net Seasonal Test Capacity is arrived at through tests of actual power production at the generator then the most likely reason for the increase is due to market demand. That is, there has been a more effective supply of power to utilities through Power Purchase Agreements (PPAs) for the capacity available at any given time.

The Net Capacity Factor calculated here on an annual basis aligns with quoted capacity factors by EIA (2019), Table 4.08.B, that uses a similar approach for calculating the ratio by dividing Net Generation by Net Summer Capacity over a given time period. The approach used here is more conservative for geothermal power as it uses both the most efficient (winter) and least efficient (summer) periods of the year and averaged total annual generation.

Geothermal power provides an “always-on” baseload electricity source (able to supply power 24 hours per day, 7 days per week). This country-wide examination of geothermal power generation is not an indication of individual power plant capacity factors that are reported at > 90% (for example: Matek and Schmidt, 2016; NREL, 2019). The Net Capacity Factor is simply a measure of efficiency resulting from two effects: 1) the power units in the entire geothermal “fleet” cannot be run at full output continuously, at their tested summer or winter seasonal capacities, without some maintenance downtime; and, 2) the power grid does not demand, or utilize, all the power that could be output continuously by all the plants. Comparing the Net Capacity Factor described above and the typical power plant capacity factor, suggests there is a total under-utilized production capacity in the USA of approximately 10% of Nameplate Capacity (see Figure 2). This assumes that 10% of the Net Capacity Factor (or approximately 7% of Nameplate Capacity) is due to maintenance downtime. The reduction in generation supplied to the grid is explained by demand-side effects and curtailment, with the under-utilization equating to approximately 380 MW country wide.

When comparing the USA to other countries then we have to imagine that similar ratios between the metrics quoted here exist for all countries across the world and are worthy of further study, as quoted “capacity factors” vary widely depending on definition. It’s likely that the value of these ratios is dependent on the mean age of the generation facilities in a particular country. For countries that have older facilities the Supply Ratio will likely be lower.

Some indication of this effect is broadly measured when taking the whole world as a test case. According to IEA (2019), the Net Generation of geothermal power for the world in 2018 was 92.7 TWh, equating to a Mean Net Generation of 10.6 GW. Compared with a reported Nameplate Capacity in 2018 of 14,600 MW by Richter (2019), then the whole world has a Supply Ratio of 73% compared with 48% for the USA.

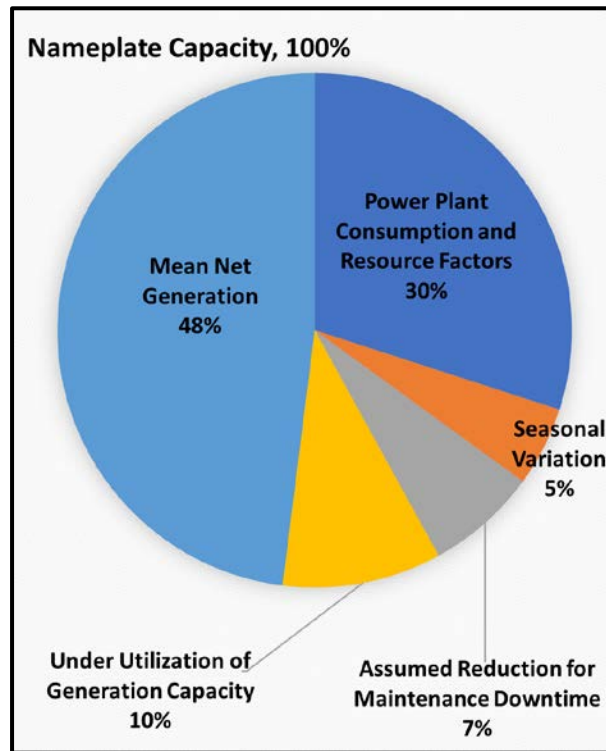


Figure 2: Illustration describing the split of Nameplate Capacity for geothermal power in the USA. Mean Net Generation is the proportion supplied to the power grid.

Again, the Net Capacity Factor and Supply Ratio are not comparable to the commonly quoted power plant capacity factor as this will change considerably from plant to plant, resource to resource, and country to country and for modern plants will likely have factors >90% in their day-to-day operations. However, these ratios are informative for assessing future strategy for installation of power on a country or regional basis, and assumptions should be tested in future international descriptions of generation data.

3. Capacity Assessment for California

3.1 Baseline Metrics

For individual states in the USA, the EIA reports only Net Summer Capacity and Net Generation. In California, Net Summer Capacity is quoted as 1,736 MW for 2018 and Net

Generation as 11,667 GWh. Using the same analysis described above, then the Mean Net Generation for California is 1,332 MW.

Another assessment of generation is provided by the California Independent System Operator (CAISO) which has responsibility for 80% of the electrical transmission system in the state (CAISO, 2020a). The daily geothermal power supplied to the grid in 2018, as recorded by CAISO Renewables Watch (CAISO, 2020b), is approximately 1000 MW. The difference between EIA and CAISO reported data means that approximately 330 MW geothermal generation capacity, an amount equal to the approximate total geothermal generation of the Imperial Valley region, is not supplied to the state’s main CAISO power grid.

Matek (2016) documents an assessment of installed Nameplate Capacity for all states with data provided by operators. This latest estimate of Nameplate Capacity is approximately 2,750 MW and is here assumed to be correct for 2018. The collection of key baseline data for the USA and California is assembled in Table 1. Note there is consistency between the ratios of Net Summer Capacity and Mean Net Generation as a function of Nameplate Capacity (see percentages) for USA and California that gives some confidence to these numbers.

Table 1: Geothermal power capacity and generation metrics for the USA and California. Percentages in parentheses are given capacities as a proportion of Nameplate Capacity.

	All of USA (MW) - 2018	California (MW) - 2018
Nameplate Capacity	3,806 MW	2,750 MW
Net Summer Capacity (measured)	2,444 MW (64%)	1,736 MW (63%)
Mean Net Generation – as a Capacity (measured)	1,823 MW (48%)	1,332 MW (48%)
Approximate CAISO Region Supply	N/A	1,000 MW (36%)

The significance for California is that any target for supply of new geothermal power requires a Nameplate Capacity target significantly larger than the supplied Mean Net Generation over the long term, assuming a conservative assessment of resource aging, production efficiencies, and supply of power outside of the targeted area.

3.2 Geothermal Target in the 2019 Integrated Resource Plan (IRP)

The current IRP modeling process performed by the CPUC aims to determine guidelines for the power mix required by California to meet its RPS and GHG emission commitments for 2030, as well as retain the reliability and resilience of the grid, whilst considering the economics of the power market. The IRP process is described further by Thomsen (2018) in the context of geothermal energy. Even though the target power mix is a guideline, it is expected that Load Serving Entities (LSEs) will closely follow the targets even though there is no current regulation to do so.

The latest IRP decision (CPUC, 2019) published in April, 2019, is a step in the right direction for geothermal as it calls for 1,700 MW net capacity of new geothermal buildout for 2030 to supply the CAISO transmission region. This is in addition to an assumed baseline of 1,200 MW net capacity of existing geothermal power supplying the same region; so a total target of 2,900 MW net capacity for 2030 – see Table 4 of CPUC (2019). The IRP uses net capacity that is supplied to the grid rather than Nameplate Capacity; that is, Mean Net Generation as defined above. The 1,200 MW of baseline supply assumed by CPUC (Thomsen, 2018) is consistent with the metrics given in Table 1 as it falls between the approximate CAISO regional supply and the Mean Net Generation for the whole of California.

The analysis of Supply Ratios and Net Capacity Factors provided earlier in this paper allows a target Nameplate Capacity to be determined and a full appreciation of the magnitude of geothermal installation that is needed. From the analysis described earlier, it is clear the Nameplate Capacity that must be installed to deliver 2,900 MW of Mean Net Generation supplied to the CAISO grid must be significantly larger. Let us consider the following assumptions in order to estimate a realistic target for Nameplate Capacity:

- 1) The assumption by CPUC that 1,200 MW of existing geothermal will still be available in 2030 is unlikely and is already at approximately 1000 MW in practice. The Mean Net Generation in California will likely decrease further as resources and power plants age and equipment is decommissioned, especially for the oldest plants. Further analysis of trends in power generation across California could yield an accurate estimate for the likely reduction. Without this analysis, an expected generation from geothermal plants existing in 2019 is assumed to be approximately 700 MW in 2030 (a 30% decrease) if no further investment into “new” resources is commissioned.
- 2) As observed in this paper, the USA has an under-utilized geothermal power of about 10% of Nameplate Capacity and California has about 320 MW of power not being supplied to the CAISO system. Can this existing power potential be supplied into the CAISO grid? Considering the nature of long-term Power Purchase Agreements (PPAs) it is assumed that none of this power could be made available.
- 3) Mean Net Generation from new geothermal power plants must therefore equal approximately 2,200 MW to meet the CPUC target (2900 MW – 700 MW of existing geothermal assumed to be remaining by 2030).
- 4) The Mean Net Generation in California is approximately 48% of the Nameplate Capacity (Table 1). As discussed earlier, for the whole world this Supply Ratio is approximately 73% - a reflection that worldwide there is an averaging of older and newer capacity. Given that build-out of geothermal power in California over the next 10 years will consist of new resources and new power plants, it can be reasonably expected that individual power plants will operate at >90% of capacity. However, this requires high performance over the longer term as a function of the theoretical nameplate capacity assigned to the power plant. To be conservative, the worldwide average of 73% is assumed as a reasonable estimate averaged over the built-out facilities and longer term. The equivalent Nameplate Capacity for a net generation from new geothermal power of 2,200 MW is therefore $(2,200 / 0.73) = 3,000$ MW.

Thus, given these assumptions, the CPUC target for total geothermal power generation in California of 2,900 MW in 2030 equates to a new build-out of approximately 3,000 MW in Nameplate Capacity plus the existing 2,750 MW. This means a Nameplate Capacity of 5,750 MW would need to be installed in California by 2030. Figure 3 illustrates the significance of this calculation.

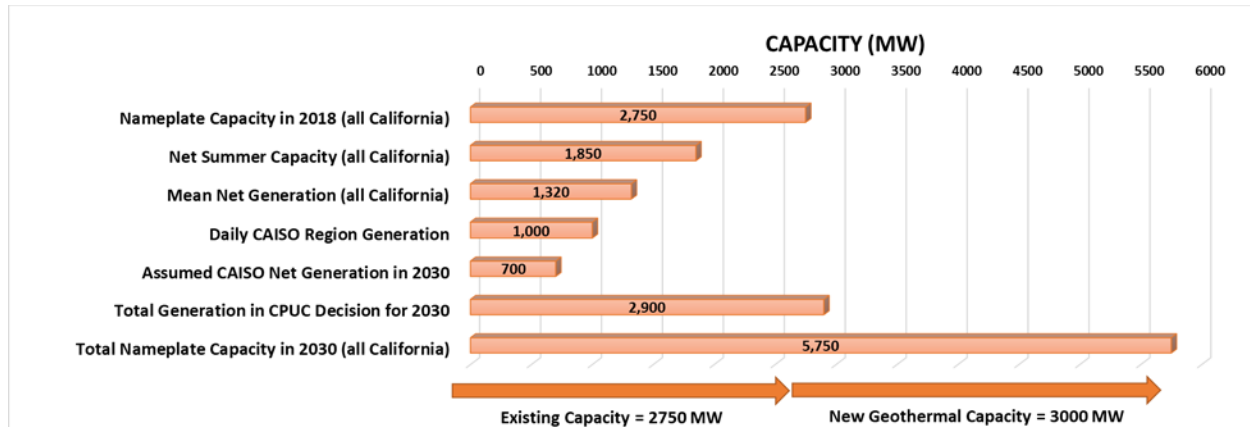


Figure 3: Illustration of Total Nameplate Capacity needed in 2030 to meet the geothermal power target presented by the California Public Utilities Commission (CPUC) in 2019.

Conclusions

This paper uses publicly available data from the EIA to form a baseline for geothermal power capacity in the USA and California so that accurate and meaningful strategies for achieving industry growth can be developed.

The paper relies on the EIA data set being accurate and complete. In 2020 the GRC and NREL have launched a parallel collaborative project to assess metrics for the state of the industry with the goals of establishing a robust data set and publishing a report in early 2021.

According to the EIA data for 2018 (the latest published) the Nameplate Capacity for geothermal power in the USA was 3,806 MW. This is consistent with previous estimates in the literature. When examining the historical EIA data, it is clear that net growth of the geothermal industry has stagnated since 2012 with only a 2.2% total growth observed over the period. For the previous 5 years (2007 – 2012) there was a total net growth of 15%. The main success for the latest six years is that the industry has not retrenched, which is significant considering that many of the existing facilities were built several decades ago. The reasons for the stagnation are likely a combination of economic and political and illustrate a need for successful strategic planning and leadership moving forward.

Capacity factors quoted in the literature and online publications vary widely, with factors for individual power plants often described as >90%. This is a reflection that the baseload supply of geothermal power from a single plant can provide energy 24 hours a day, 365 days per year with minimal interruptions for maintenance and is thus an excellent replacement for nuclear, coal and gas. In practice, power supplied to the grid is a complicated system and interpretation of the numbers can be confusing. For instance, Nameplate Capacity is a theoretical stamp marking a

given power plant's maximum output and does not reflect the actual output that is supplied to the grid. Nameplate Capacity is useful as it provides a consistent baseline for setting strategic objectives and comparing theoretical energy sources and geographical regions.

When data from the EIA is examined objectively and holistically, the net summer and winter capacities are a more accurate quantification of the maximum operational power that can be supplied to the grid, as they are measured through short term tests at the generator. For geothermal energy, the difference in net summer and winter capacities reflects the differences in seasonal efficiencies with geothermal power supplying greater output in the winter. This effect makes geothermal power an excellent substitute for the reduction in solar power output during those winter months, meaning that hybrid use of solar, geothermal and storage combined is likely an effective strategy for facilitating stable market penetration of renewable energy. A Net Seasonal Test Capacity is defined as the mean of the two seasonal capacity tests. In 2018 the Net Seasonal Test Capacity is 2,611 MW for the USA. The 30% difference from the Nameplate Capacity is caused by power plant consumption and resource factors averaged over all the geothermal power plants in the country.

The actual power output to the grid averaged over the 2018 calendar year, the Mean Net Generation, was 1,823 MW. Two important performance ratios are defined in this paper for consideration in forward strategic planning. The first is a Net Capacity Factor that is the ratio of the Mean Net Generation and the Net Seasonal Test Capacity. Since reaching a minimum in 2012, it's observed that this ratio has been increasing to approximately 70% - a result that aligns with a similar EIA recognized calculation for "capacity factor". This increase is interpreted here to be due to more effective supply of power to utilities through PPAs for the capacity available at any given time.

The second ratio is a Supply Ratio calculated as the Mean Net Generation to Nameplate Capacity. The Supply Ratio allows a forward calculation of capacity required for installation for a given target power generation. In 2018, the Supply Ratio for the USA was 48%. The same ratio for worldwide geothermal power was 73%, with the difference likely reflecting the older industry in the USA. When comparing the Supply Ratio and Net Capacity Factor there is a 10% underutilization of existing geothermal power in the USA that is equivalent to approximately 380 MW, probably due to demand-side effects and curtailment. This means there's still room for the Net Capacity Factor to increase to > 80%.

The importance of these ratios comes into play when examining strategic goals for building out geothermal power in California. The latest CPUC recommendation calls for 2,900 MW net capacity supplying the CAISO transmission region in 2030. This target includes existing and new geothermal installations. As this target uses Mean Net Generation then it is clear from the ratios above that the actual Nameplate Capacity needed is significantly higher. Considering several assumptions, including aging of facilities and capacity factors for new plants, the total installed Nameplate Capacity in California needs to be approximately 5,750 MW in 2030 to achieve the CPUC target.

How can the geothermal industry achieve 3 GW of new power supply to CAISO before 2030?

There is not a resource limitation in California for achieving this goal and technologies exist to supply the power. Ultimately the answer comes in the form of what dollar investment is needed

to develop the resources and how to achieve a return on that investment, so that PPAs can be agreed and development loans secured. To assess investment needs requires an appreciation for regulatory and policy hurdles that must be overcome, a strategic review of what specific resources should be built-out, and an understanding of where investment opportunities can be successfully developed. These tasks will require input from talented people across several disciplines and industries. Thus, one effective approach to answering this question is to establish a well-funded and industry-led strategic task force with the goal of planning sufficient geothermal installation over the next 10 years.

Glossary of Introduced Terms

Mean Net Generation: Net Generation expressed as power capacity by assuming the entirety of the annual generation is equally spread throughout the year, 24 hours per day.

Net Seasonal Test Capacity: the mean of Net Summer Capacity and Net Winter Capacity for a given year.

Net Capacity Factor: the ratio of the Mean Net Generation to the Net Seasonal Test Capacity.

Supply Ratio: the ratio of Mean Net Generation to Nameplate Capacity.

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