PROCEEDINGS, 45th Workshop on Geothermal Reservoir Engineering
Stanford University, Stanford, California, February 10-12, 2020
SGP-TR-216

35 Years of Geothermal Power Generation in Nevada, USA: A Review of Field Development, Generation, and Production Histories

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Keywords: Nevada; power generation; field development; history; production; Great Basin

ABSTRACT

Geothermal electricity generation began in Nevada in 1984, with the commissioning of the ~ 1.2 MWe plant at Wabuska. Since then, 26 geothermal power plants have been built, with a total installed nameplate capacity of ~770 MWe (~520 MWe gross) in 2018. The share of geothermal electricity generation in the state increased from < 4% in 1990 to 8.7% in 2018. Average fluid production temperatures at the wellhead for Nevada's geothermal plants range from ~97 – 187 °C (207 – 369 °F) for electricity generation, and three reported direct-use applications use geothermal fluids ranging between 78 – 95 °C (172 – 203 °F). Due to the moderate to low resource temperatures of most geothermal systems in the Great Basin, and the groundwater resource challenges in its arid environment, most power plants are using closed-loop, binary-cycle systems, with only three operating flash plant systems. Production flow rates for an individual well average 130 liters/second (l/s; ~2,060 gallons/minute (gpm)) for electricity generation, with the highest average production flowrates measured at the Don A. Campbell geothermal field (315 l/s; 4,993 gpm). Reviewing trends in electricity generation over time, it is apparent that some fields have experienced periods of production decline (e.g. San Emidio, Brady Hot Springs, Stillwater, Soda Lake and Salt Wells), whereas others demonstrate relatively stable generation, including Dixie Valley, Wabuska, Steamboat Hills, Jersey Valley, and Beowawe. In the last decade, three geothermal sites have installed combined solar-geothermal systems to offset the effects of diurnal and seasonal changes in climate that reduce overall binary plant efficiency. Such efforts have proven successful and may become more common for future plant installations.

1. INTRODUCTION

Nevada contains abundant hydrothermal geothermal resources, with mean estimates of identified and undiscovered hydrothermal resources totaling 5,755 MWe (Williams et al., 2008). With just over 10% of this potential resource base developed to date, the opportunity for further development in the future is substantial. Barriers to increased development include resource exploration risk (i.e. confirming temperature and permeability): estimates indicate that ~ 40% of known geothermal systems in the Great Basin are blind systems with no surface expression (Faulds and Hinz, 2015). Other studies have speculated that as much as 75% of our undiscovered systems may be blind (Coolbaugh et al., 2006). Advances in exploration technologies to improve exploration success, application of lessons learned about reservoir behavior and field sustainability from currently-producing fields, and continued enactment of supportive state and federal policies and regulations that encourage geothermal energy development are required to fully realize the Great Basin's resource potential.

This paper reviews drilling data, production data and electricity generation trends for Nevada's geothermal fields, with data sourced from the Nevada Division of Minerals (as provided by the field operators), and data compilations hosted (and being updated) by the Great Basin Center for Geothermal Energy at the University of Nevada, Reno. Summaries and evaluations of some of these data are also presented in the Nevada mineral industry report prepared annually by the Nevada Bureau of Mines and Geology (e.g. Muntean et al., 2017, 2018).

2. GEOTHERMAL GENERATION IN NEVADA AT PRESENT

There are seventeen geothermal fields producing electricity in Nevada as of January 2020 (Table 1; Figure 1). The largest geothermal field in Nevada is McGinness Hills in Lander County: this system now has three 48 MWe power plants installed, with a total gross generation capacity of over 150 MWe. Most of the geothermal fields have a single geothermal plant on site, but five have two or more plants: the Steamboat geothermal field (including Steamboat Hills and lower Steamboat) that currently has six operating plants; Dixie Valley (two plants); Soda Lake (two plants); McGinness Hills (three plants), and Don. A. Campbell (two plants). The Dixie Valley geothermal plant has a flash plant, and small binary unit: this unit is not routinely used. Soda Lake has two installed plants that were commissioned in 1987 and 1991, but Cyrq Energy are completing a repowering at present to replace the two plants with a new air-cooled Ormat Energy Converter (OEC) that will form the Soda Lake 3 plant. Most fields are using binary geothermal power plants, which are more efficient at lower resource temperatures and require minimal consumptive water use (in contrast to flash plants). Beowawe, Dixie Valley and Steamboat Hills are the remaining operating flash plants in the state. The Steamboat Hills flash plant is planned to be replaced with one of Ormat's Energy Converters (OEC) in 2020, thus modifying it to a binary-cycle plant. Three fields with binary-cycle plants are also connected to solar photo-voltaic (PV) arrays: Stillwater (which also has a solar-thermal array), Patua, and Tungsten Mountain. Such pairing of geothermal and solar has advantages in the Nevada desert: during summer months and warmer daytime temperatures, air-cooled heat exchangers perform at a lower efficiency, and net power generation drops. Solar PV generation during the same warmer times helps to balance the daily generation cycle, and somewhat offset the decrease in net generation during summer months.

Table 1: Nevada geothermal power plants, and electricity generation figures: 2018.

Plant name	Nameplate Capacity (MWe)[1]	Flash or Binary	Commission Year	2018 Generation (MWhr)		2018 Generation (MWe)[2]		Operator
				Gross	Net	Gross	Net MWe	
Beowawe	18.5	F/B	1985	120,338	99,494	13.7	11.4	Terra-Gen Power
Blue Mountain	49.5	B	2009	329,811	229,192	37.6	26.2	AltaRock Energy
Brady Hot Springs	26.1	B	1992	118,526	77,744	13.5	8.9	Ormat Nevada Inc.
Desert Peak II	23.0	B	2006	122,132	91,540	13.9	10.4	Ormat Nevada Inc.
Dixie Valley	64.7	F	1988	556,826	495,759	63.6	56.6	TerraGen Power, LLC
Dixie Valley Binary Unit	6.2	B	2012			0.0	0.0	TerraGen Power, LLC
Don A. Campbell	22.5	B	2013	197,427	164,059	22.5	18.7	Ormat Nevada Inc.
Don A. Campbell II	25.0	B	2015	192,838	151,448	22.0	17.3	Ormat Nevada Inc.
Jersey Valley	23.5	B	2011	109,964	73,199	12.6	8.4	Ormat Nevada Inc.
McGinness Hills	48.0	B	2012	440,324	368,282	50.3	42.0	Ormat Nevada Inc.
McGinness Hills II	48.0	B	2015	445,349	375,442	50.8	42.9	Ormat Nevada Inc.
McGinness Hills III	48.0	B	2018	40,336	33,644	4.6*	3.8*	Ormat Nevada Inc.
Patua	48.0	B	2012	202,752	192,148	23.1	21.9	Cyrq Energy
Salt Wells	23.6	B	2009	141,524	98,687	16.2	11.3	Enel North America
San Emidio	11.75	B	2012	90,206	65,429	10.30	7.47	Ormat Nevada Inc.
Soda Lake No. 1	5.1	B	1987	29,666	18,970	3.4	2.2	Cyrq Energy
Soda Lake No. 2	21.0	B	1991	69,551	41,702	7.9	4.8	Cyrq Energy
Steamboat II	23.9	B	1992	89,279	53,885	10.2	6.2	Ormat Nevada Inc.
Steamboat III	23.9	B	1992	98,291	61,723	11.2	7.0	Ormat Nevada Inc.
Galena 1	30.0	B	2005	165,477	134,778	18.9	15.4	Ormat Nevada Inc.
Galena 2	13.5	B	2007	62,115	71,556	7.1	8.2	Ormat Nevada Inc.
Burdette (Galena 3)	30.0	B	2008	171,338	129,452	19.6	14.8	Ormat Nevada Inc.
Steamboat Hills	13.2	F	1988	103,354	89,827	11.8	10.3	Ormat Nevada Inc.
Stillwater 2	47.2	B	2009	196,203	123,749	22.4	14.1	Enel Stillwater
Tungsten Mountain	37.0	B	2017	255,673	207,954	29.2	23.7	Ormat Nevada Inc.
Tuscarora	32.0	B	2012	177,070	125,567	20.2	14.3	Ormat Nevada Inc.
Wabuska	5.6	B	1984	17,805	11,990	2.0	1.4	Open Mountain Energy
Total:	**768.8**			**4,544,175**	**3,587,219**	**518.7**	**409.5**	

[1] Nameplate capacity is the manufacturer's rating of equipment output capacity, as reported to the Nevada Division of Minerals by the plant operators, and does not necessarily reflect the capability of the currently developed resource. These nameplate capacities are estimates, and several different values can be found in the literature. Generator nameplate capacity actually refers to the size of the actual generator, but not to the turbine size or the actual capacity of the power plant. There are no public documents breaking down nameplate capacity of the turbines or gross power, so these numbers may not adequately reflect actual generation.

[2] Generation values were calculated by dividing annual megawatt hours (MWh) produced by the number of hours in a year.

* McGinness Hills III plant came online in late 2018, thus the calculated MWe for the year only reflects ~1 month of generation.

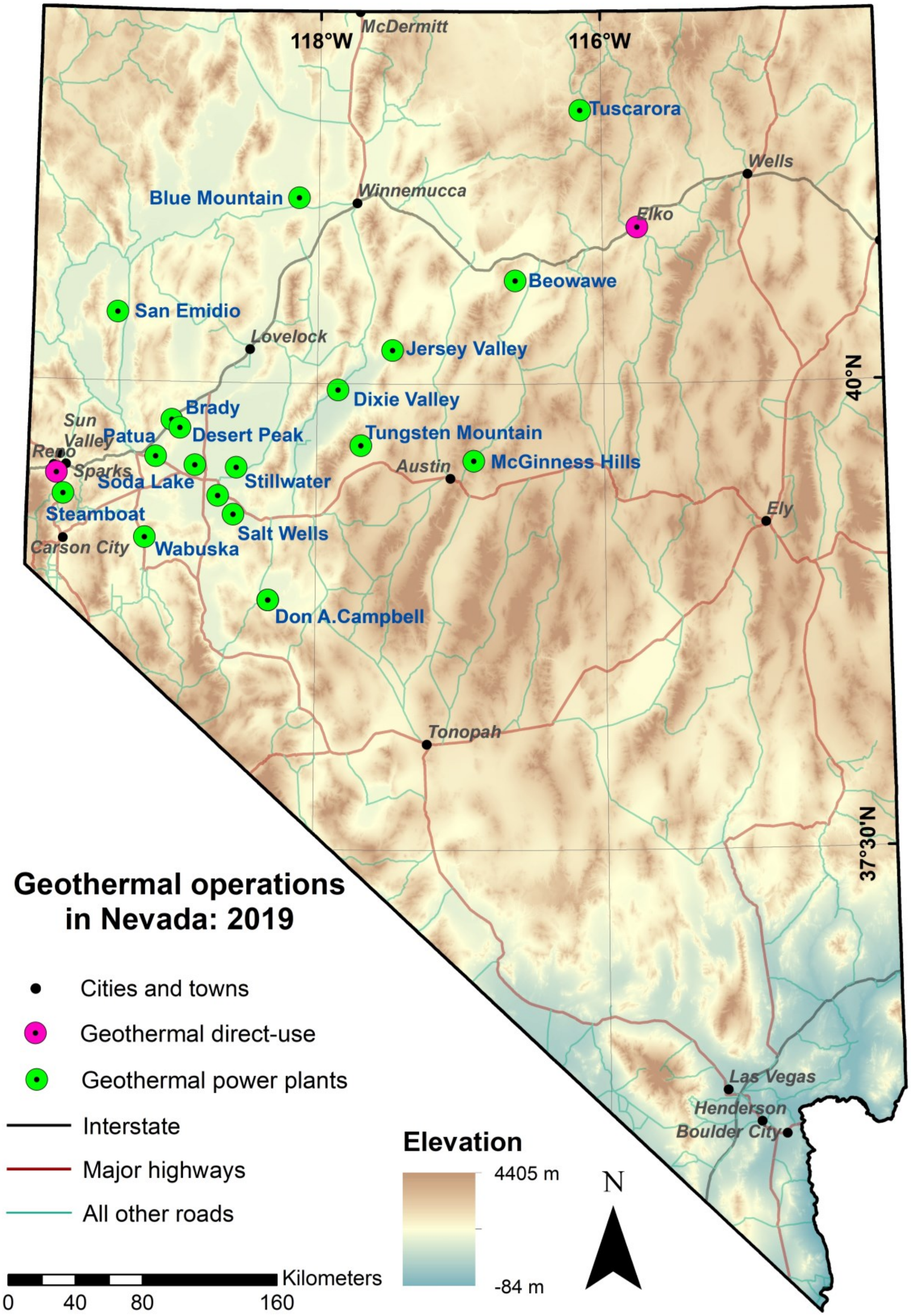

Figure 1: Location of producing geothermal power plants and direct-use applications in Nevada, 2019.

3. HISTORICAL TRENDS IN GEOTHERMAL EXPLORATION

Over 2,200 hundred wells have been drilled in Nevada for geothermal purposes (which are included in the GBCGE well header database), but approximately 700 of these wells have incomplete meta-data and are missing spud date or well completion date. Reviewing trends for wells with drilling-date constraints, the earliest geothermal exploration in Nevada apparently started in the late 1940's, with the USGS drilling thirteen shallow auger holes (less than five meters deep) and eight thermal gradient wells at the Steamboat geothermal area. In the early to mid 1960's, Columbia Iron Mining Co. drilled 50 test holes in the Carson Valley (typically less than 40 m deep). Efforts accelerated from the mid 1970's until the mid 1980's, with initial efforts led by oil and gas companies who were pursuing geothermal, including Earth Power Production Co., Chevron Oil Co. and Amax Exploration, Inc. In 1979, over 100 wells were drilled for geothermal purposes (Figure 2): most of these were shallow thermal gradient holes. This intensity of geothermal drilling has not occurred again since. From 1980 onwards, increased numbers of geothermal production wells were drilled, followed soon after by increases in installed geothermal capacity and power generation (Figure 2, lower graph). From the mid 1990's to mid 2000's, drilling of geothermal wells decreased, until the next boom that occurred from the mid – late 2000's. The greatest number of production wells were drilled in this period, with over 100 production wells drilled between 2005 and 2012. Net electricity production doubled over the same time period (Figure 2).

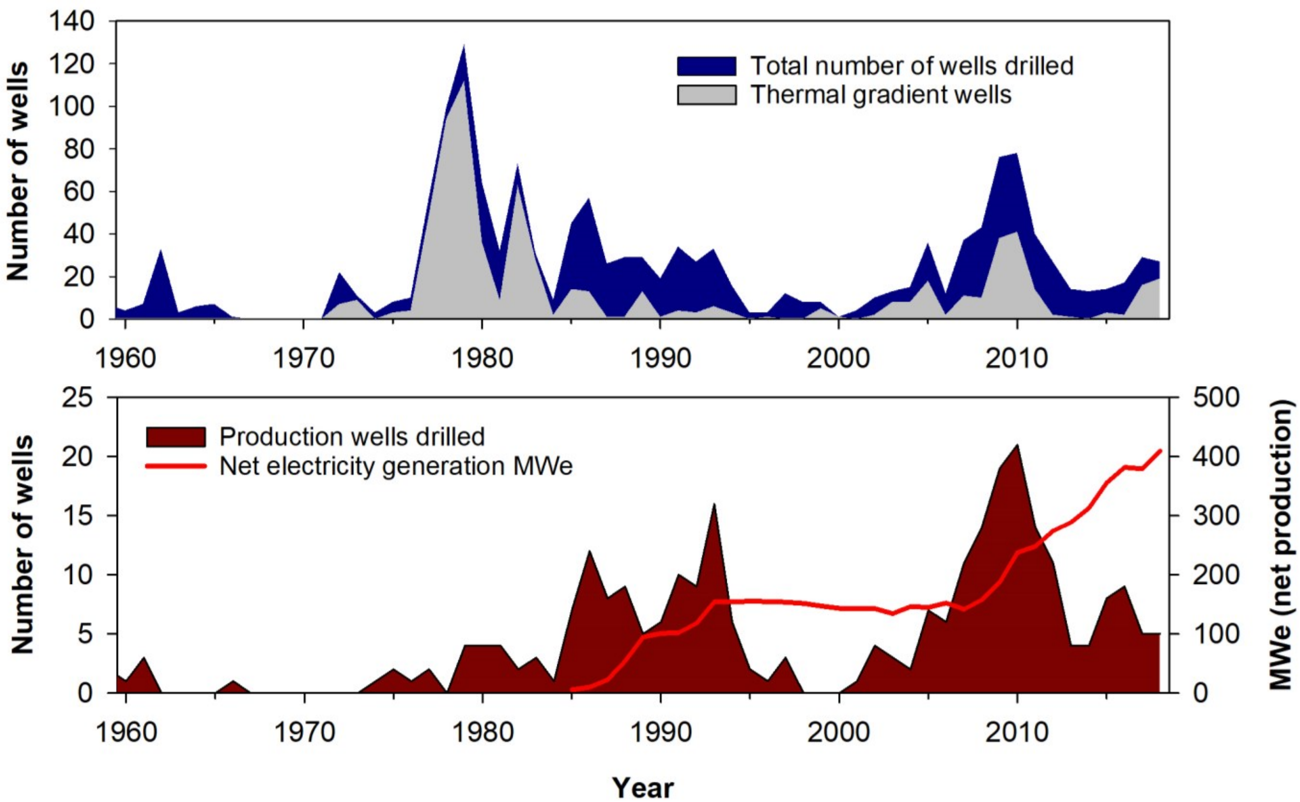

Figure 2: Trends in geothermal drilling activity in NV since 1960. Top panel: total number of wells, and thermal gradient wells. Bottom panel: Number of geothermal production wells, and the total net geothermal power generation in megaWatts (electric). Data sourced from the GBCGE geothermal database, and including data provided by NDOM.

Reviewing the drilling depths of the geothermal wells drilled, we observe that the deepest well drilled for geothermal or temperature measurement purposes was almost 4,700 m deep, drilled in Railroad Valley in 1986. However most wells are less than 1,000 m deep (Figure 3). The median drilled depth of production wells is ~900 m. Fields that are dominated by production wells deeper than 2,500 m include (from deepest to shallowest): Dixie Valley, Patua, Beowawe, and Soda Lake. The fields will shallowest production wells (less than 500 m) include Steamboat, San Emidio, Wabuska, and Salt Wells.

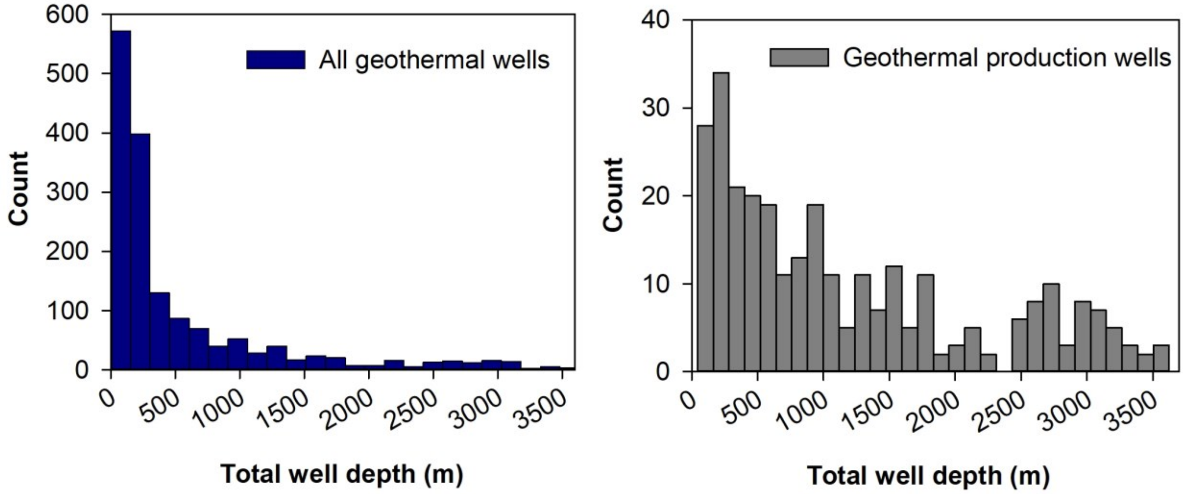

Figure 3: Histograms of drilling depths of geothermal wells in Nevada: all geothermal wells drilled (left), and production wells (right). Data sourced from the GBCGE geothermal database, and including data provided by NDOM.

4. HISTORIAL TRENDS IN GEOTHERMAL ELECTRICITY GENERATION

After the first geothermal exploration wells were drilled in Nevada in the late 1940's and 1950's, the first commercial use of geothermal heat was for vegetable dehydration at Brady Hot Springs in 1979. The first geothermal plant in Nevada began operation in late 1984 (Wabuska), and since then, 16 other systems have been developed for geothermal electricity generation. While total installed nameplate capacity has increased to almost 800 MWe in 2018, the net generation to market is just over 400 MWe (Figure 4). Gross generation in 2018 was approximately 520 MWe, with the difference between gross and net reflecting the parasitic losses of energy required to operate the geothermal plant (injection and downhole production pumps etc.). Over the same time period, the average cost of geothermal generation has varied between ~6 to 8 c/kWhr.

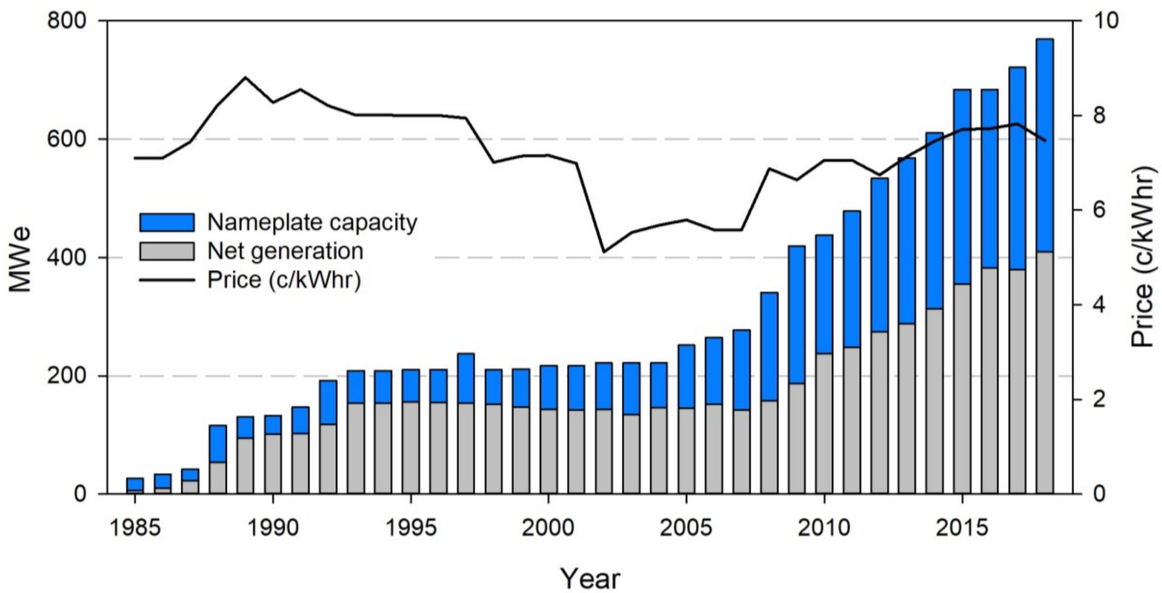

Figure 4: Cumulative nameplate generating capacity, net geothermal power generation, and average sale price of geothermal power in Nevada between 1985 and 2018, as reported to the Nevada Division of Minerals. Net generation is calculated by dividing annual net generation in megawatt-hours by the number of hours in a year.

Several plants generate electricity that is sold to California under power purchase agreements (PPA's). In 2017, Ormat Nevada Inc. secured a new PPA with the Southern California Public Power Authority (SCPPA) for a term of 26 years beginning December 31, 2017[1], with a fixed price of $75.50/MWh. SCPPA in turn sell this power to the Los Angeles Department of Water and Power (LADWP). Energy deliveries began in December 2017, and the entire portfolio is expected to be online in 2022. The portfolio PPA

[1] https://investor.ormat.com/file/Index?KeyFile=2000842054

contract is for 150 MWe but has an upper capacity limit of 185 MWe net and lower limit of 135 MWe net. This additional capacity will be met by a combination of generation from new geothermal plants (e.g. Tungsten Mountain, Dixie Meadows, Baltazor Hot Springs, McGinness Hills Phase 3 expansion), as well as re-contracting of existing plants (e.g. Steamboat Hills, Brady, Steamboat 2 and 3, and Desert Peak). Terra-Gen Power has a PPA with Southern California Edison (SCE) and sells its power from the Dixie Valley geothermal plant. Cyrq Energy sells its power from the Patua geothermal plant to the Sacramento Municipal Utility District (SMUD) under a 21-year PPA.

As Nevada's demand for electricity has increased, in-state electricity generation has also increased, from ~20×10^6 MWhrs in 1990 to double this in 2018 (Figure 5). During this time, there have been some important shifts in the energy sources contributing to this generation, from being coal-dominated from 1990 until the mid-2000's, to being natural gas-dominated since then and through to present day. Geothermal and hydroelectric energy sources have remained steady contributors to Nevada's generation portfolio over the same time interval. Electricity generation from solar sources has increased rapidly over the last 5 years, and now comprises ~10% of Nevada's generation portfolio (Figure 5). A small fraction of this solar is generated from three geothermal plants that have solar-PV arrays connected. Tungsten Mountain has a 7 MWe solar PV array, Stillwater has a 26 MWe solar PV array and a 2 MWe (17 MWth) solar thermal array, and Patua has a 14.5 MWe solar PV array to supplement the geothermal electricity generation.

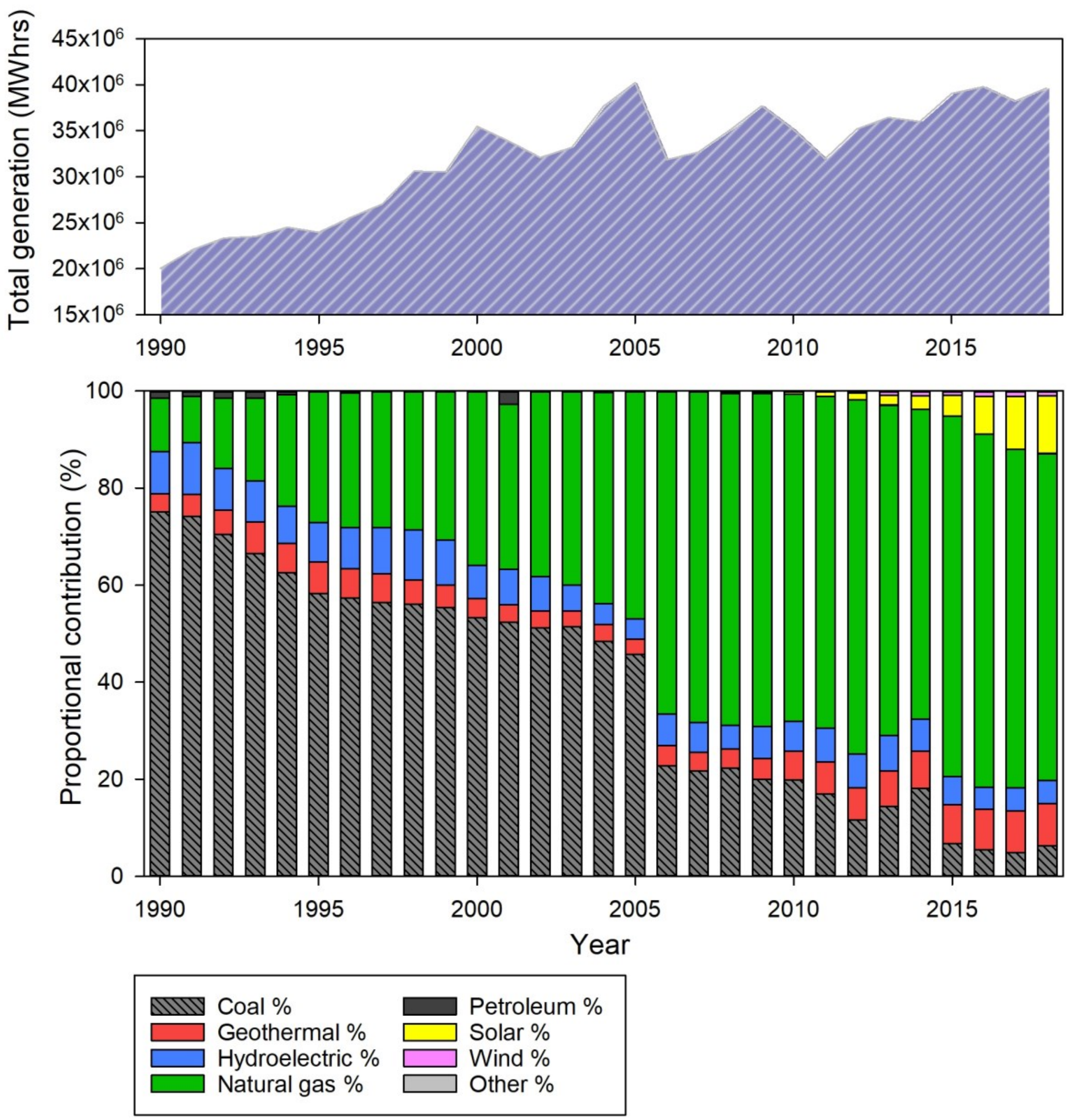

Figure 5: Trends in Nevada's electricity total generation and proportional contribution of various energy sources, 1990 - 2018. (Data sourced from the U.S. Energy Information Administration https://www.eia.gov/electricity/state/Nevada/)

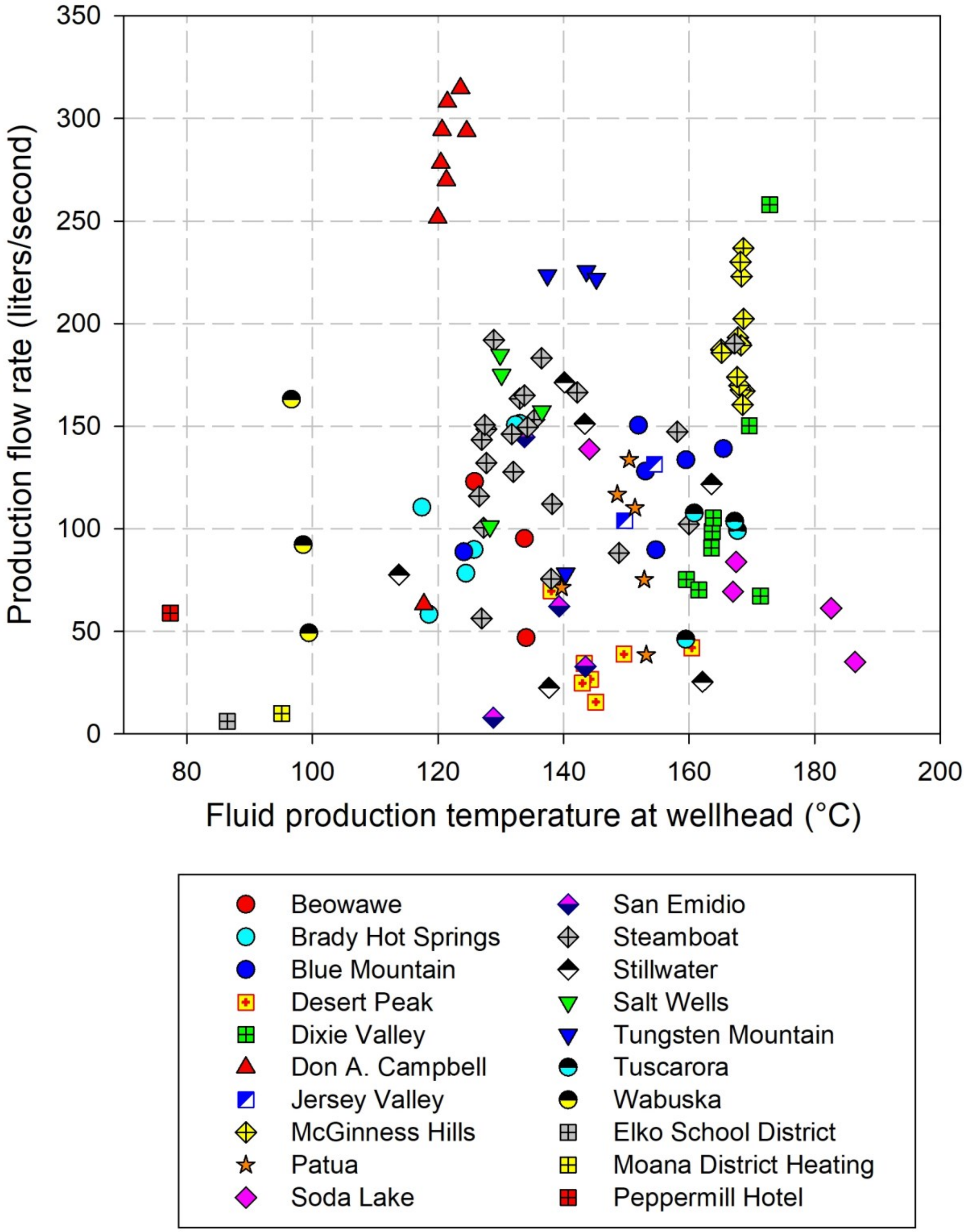

Figure 6: Average production flow rates of geothermal wells in Nevada in 2018 and their associated temperatures as measured at the wellhead. Data compiled based on information provided to the Nevada Division of Minerals, 2018.

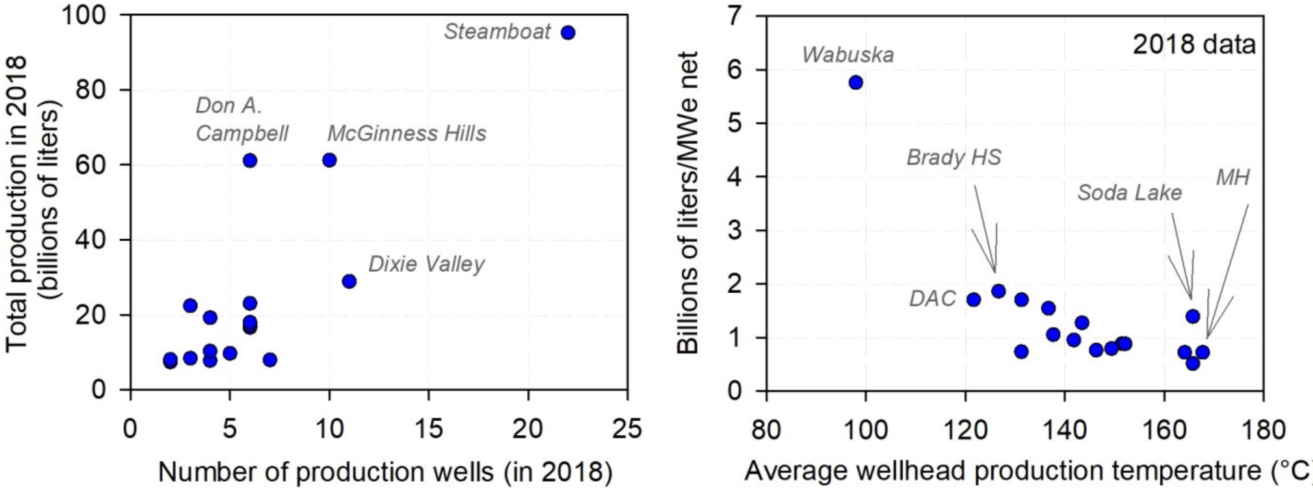

Figure 7: Comparison of total geothermal fluid production in 2018 for Nevada's electricity-generating fields and number of production wells active in 2018 for each field (left plot), and relationship between average wellhead production temperature (averaged between all production wells) and amount of fluid production required per MWe (net) generation (right plot). Note: Well count and production volumes for McGinness Hills only includes plants 1 and 2 for 2018: plant 3 began commercial production in December 2018.

In 2018, the average fluid production temperatures at the wellhead for Nevada's geothermal plants ranged from ~97 – 187 °C (207 – 369 °F) for electricity generation, and three reported direct-use applications used geothermal fluids ranging between 78 – 95 °C (172 – 203 °F) (Figure 6). Production flow rates for an individual well averaged 130 liters/second (l/s; ~2,060 gallons/minute (gpm)) for electricity generation, with the highest production flowrates measured at the Don A. Campbell geothermal field (315 l/s; 4,993 gpm). With the exception of one well in Dixie Valley, seven out of the eight production wells at Don A. Campbell are the highest producing wells in the state, and are also producing some of the lowest temperature geothermal fluids (~ 120 - 125 °C). Productions wells at the McGinness Hills geothermal field also have consistently high productivity (Figure 6).

Data provided to the Nevada Division of Minerals indicate that the Steamboat geothermal plants had the greatest number of active production wells (over 20) and produced the highest volume of geothermal fluid in 2018 for electricity generation – almost 100 billion liters (Figure 7). The next highest producers were the Don A. Campbell and McGinness Hills geothermal plants. When the McGinness Hills geothermal plant has 12 full months of production data available (from 2019), it may exceed even the Steamboat plant and become the highest producing plant in the state for annual fluid production volumes. Evaluating the liters of fluid produced for each field per megawatt of electricity produced, the Wabuska plant is distinct, with the largest produced fluid volumes and almost 6 billion liters of fluid produced per MWe generated in 2018. Wabuska also produces the lowest temperature fluid of all geothermal power plants in the state, thus larger production volumes are required for thermal energy extraction and conversion. McGinness Hills has the highest average wellhead temperature, and is associated with some of the lowest fluid production volumes per MWe generated.

Some fields have experienced periods of production decline since commissioning – these include San Emidio, Brady Hot Springs, Stillwater, Soda Lake and Salt Wells. Other fields have demonstrated relatively stable generation, including Dixie Valley, Wabuska, Steamboat Hills, Jersey Valley, and Beowawe (Figures 8a,b,c). In some fields, operators have attempted to address production decline by modifying field production and injection strategies to reduce or slow down communication between injection and production wells (e.g. Tuscarora; Chabora et al., 2015), and others have re-powered existing (older) plants with newer, more-efficient plants (e.g. Brady Hot Springs was repowered in 2018, and produced an additional 4 MWe). The San Emidio plant was re-powered in 2012, with a new 12 MWe plant replacing the older 4.5 MWe plant. While such re-powering helps to boost power output in the short term, it may not address the issue of continued thermal or production decline. Continued work to understand and evaluate conceptual models of geothermal systems in the Great Basin may help to improve/optimize field development strategies, and also lead to improved understanding of system sensitivities and vulnerabilities to production.

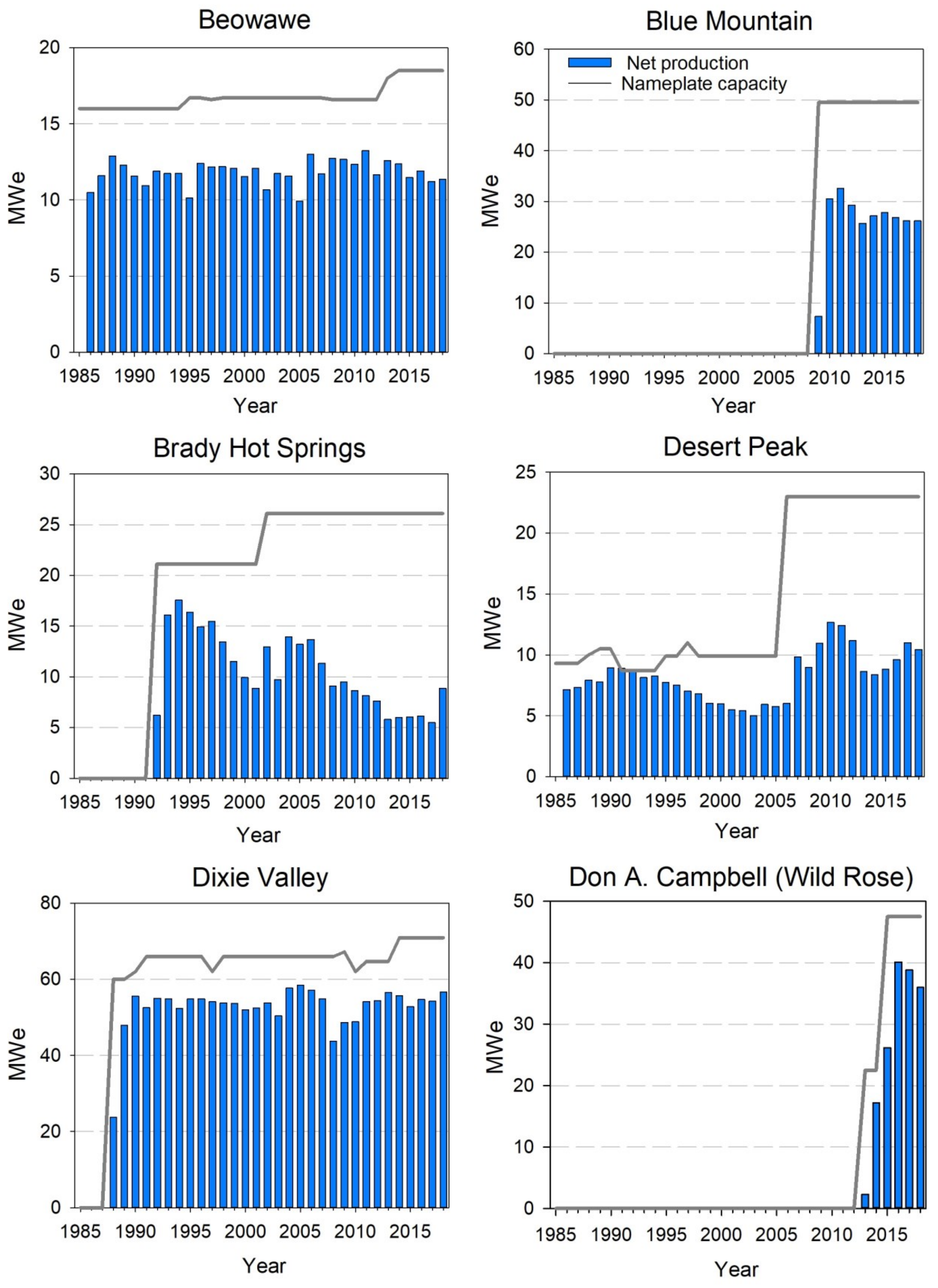

Figure 8a: Trends in net field generation and installed nameplate capacity (MWe) for geothermal power plants in Nevada (legend is the same for all plots). Data sourced from the Nevada Division of Minerals (NDOM).

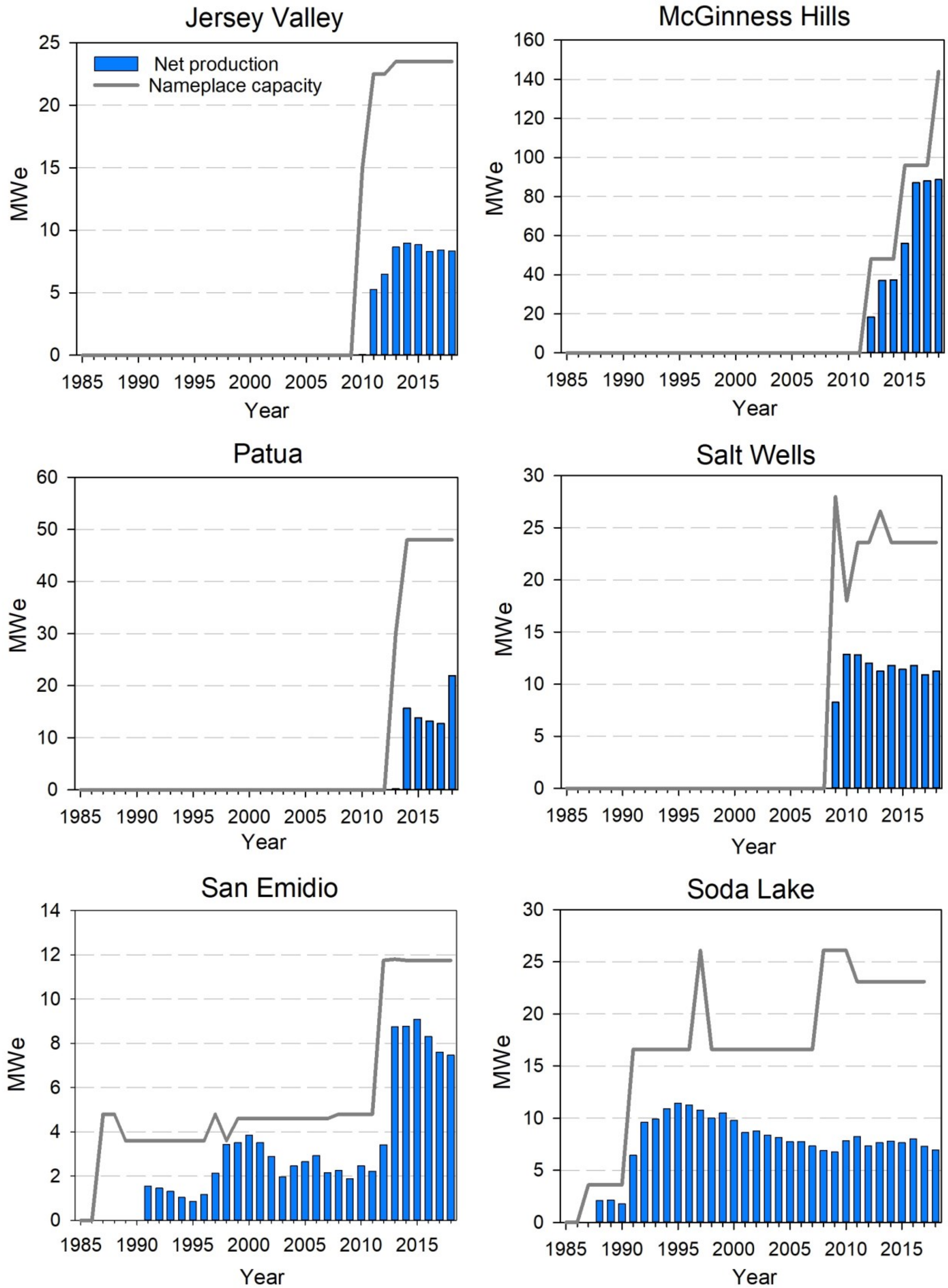

Figure 8b: Trends in net field generation and installed nameplate capacity (MWe) for geothermal power plants in Nevada (legend is the same for all plots). Data sourced from the Nevada Division of Minerals (NDOM).

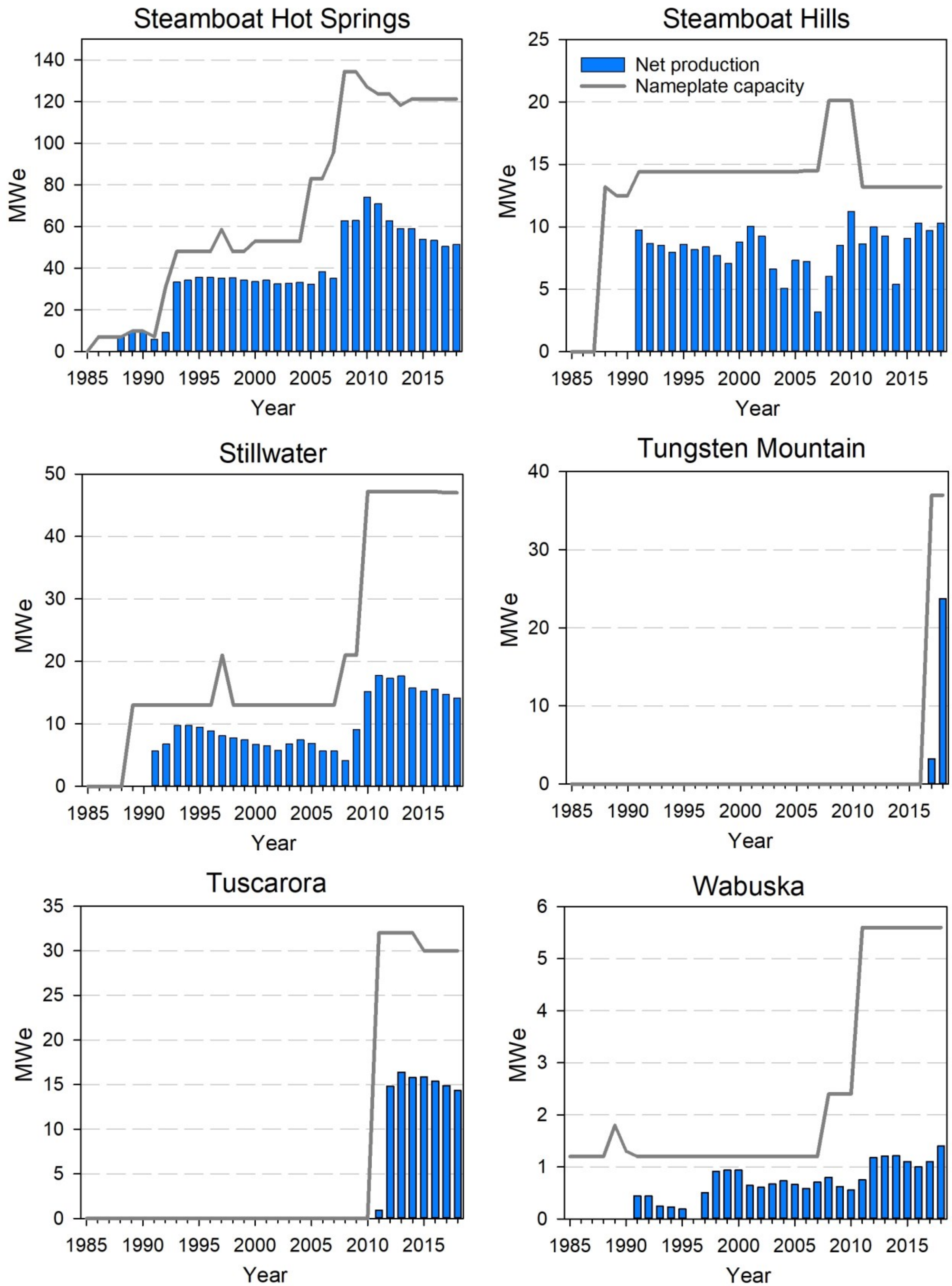

Figure 8c: Trends in net field generation and installed nameplate capacity (MWe) for geothermal power plants in Nevada (legend is the same for all plots). Data sourced from the Nevada Division of Minerals (NDOM).

5. SUMMARY

Nevada has a rich geothermal exploration and development history, and the sizeable estimated known and undiscovered resource base offers the potential for geothermal energy resources to make a much larger contribution to Nevada's (and California's) electricity generation portfolio. Through lessons learned with maintaining stable, long-term production for existing fields, and innovations that combine geothermal generation with solar PV and solar thermal generation, the future looks promising for the sector. Tracking production trends and other such data helps to evaluate field behavior on a regional scale, and may improve our understanding of system dynamics, sensitivities, and best approaches to ensure continued sustainable production from these Great Basin geothermal reservoirs.

ACKNOWLEDGEMENTS

Lowell Price at the Nevada Division of Minerals is thanked for provision of geothermal well datasets including production and injection data. Elijah Mlawsky at the Great Basin Center for Geothermal Energy helped to collate well data from NDOM and other sources.

REFERENCES

Chabora, E., Lovekin, J., Spielman, P., Krieger, Z.: Resource Performance at Ormat's Tuscarora Geothermal Project, Nevada USA. *Proceedings*, World Geothermal Congress, **(2015),** Melbourne, Australia, 19-25 April 2015.

Coolbaugh, M.F., Raines, G.L., Zehner, R.E., Shevenell, L., and Williams, C.F.: Prediction and discovery of new geothermal resources in the Great Basin: Multiple evidence of a large undiscovered resource base. *Transactions*, Geothermal Resources Council, 30, **(2006),** p. 867-873.

Faulds, J.E., and Hinz, N.H.: Favorable Tectonic and Structural Settings of Geothermal Systems in the Great Basin Region, Western USA: Proxies for Discovering Blind Geothermal Systems. *Proceedings*, World Geothermal Congress, **(2015),** Melbourne, Australia, 19-25 April 2015.

Muntean, J. L., Davis, D., Ayling, B. F.: The Nevada Mineral Industry 2017. NBMG Special Publication, **(2018),** 212 p.

Muntean, J. L., Davis, D., Ayling, B. F.: The Nevada Mineral Industry 2018. NBMG Special Publication, **(2019).**

Williams, C.F., Reed, M.J., Mariner, R.H., DeAngelo, J., Galanis, P.: Assessment of Moderate- and High-Temperature Geothermal Resources of the United States. USGS Factsheet, **(2008),** Fact sheet 2008-3082, 4p.