DOCKETED	
Docket Number:	19-IEPR-02
Project Title:	Electricity Resource Plans
TN #:	225588
Document Title:	Staff Paper - Thermal Efficiency of Natural Gas-Fired Generation in California 2018 Update
Description:	*** THIS DOCUMENT SUPERSEDES TN 225562 ***
Filer:	Harinder Kaur
Organization:	California Energy Commission
Submitter Role:	Commission Staff
Submission Date:	10/30/2018 2:53:51 PM
Docketed Date:	10/30/2018

STAFF PAPER

Thermal Efficiency of Natural Gas-Fired Generation in California: 2018 Update

Michael Nyberg

Supply Analysis Office

Energy Assessments Division

California Energy Commission

California Energy Commission

Edmund G. Brown Jr., Governor

October 2018 | CEC-200-2018-011

DISCLAIMER

Staff members of the California Energy Commission prepared this report. As such, it does not necessarily represent the views of the Energy Commission, its employees, or the State of California. The Energy Commission, the State of California, its employees, contractors and subcontractors make no warrant, express or implied, and assume no legal liability for the information in this report; nor does any party represent that the uses of this information will not infringe upon privately owned rights. This report has not been approved or disapproved by the Energy Commission nor has the Commission passed upon the accuracy or adequacy of the information in this report.

ABSTRACT

Senate Bill 1389 (Bowen and Sher, Chapter 568, Statutes of 2002) directed the California Energy Commission to adopt an *Integrated Energy Policy Report* (*IEPR*) every two years. This staff paper supports the *IEPR* technical analyses by describing general trends in the average thermal efficiency of natural gas-fired generation in California from 2001 through 2017. Over this 17-year period, California's systemwide thermal efficiency improved by 22 percent due to the successful development of new combined-cycle power plants. The leveling off of gains in thermal efficiency in recent years is due to the rapid growth of utility-scale and distributed solar photovoltaic generation reducing the usage of gas-fired generation. Thermal efficiency was also negatively impacted by the return of significant hydroelectric generation after an extended multiyear drought. In 2017, California's non-greenhouse gas-emitting electric generation accounted for more than 56 percent of total in-state generation, compared to 50 percent in 2016.

Keywords: Combined cycle, heat rate, gas-fired generation, thermal efficiency

Nyberg, Michael. 2018. *Thermal Efficiency of Natural Gas-Fired Generation in California: 2018 Update*. California Energy Commission. CEC-200-2018-011

TABLE OF CONTENTS

Page

LIST OF FIGURES

Page

LIST OF TABLES

Page

CHAPTER 1: Thermal Efficiency

Introduction

"Data are facts or figures from which conclusions may be drawn."[1]

This staff paper, the seventh in a series, describes the general trends in the average thermal efficiency of natural gas-fired generation in California from 2001 through 2017. The paper provides an overview of California's total electric generation profile and examines some of the underlying elements that directly impact the observed thermal efficiency. The impetus for this paper stems from the requirements of Senate Bill 1389 (Bowen and Sher, Chapter 568, Statutes of 2002), which directs the California Energy Commission to adopt an *Integrated Energy Policy Report* (*IEPR*) every two years. Documenting changes in the state's thermal efficiency helps inform policy makers charged with guiding energy procurement decisions and overseeing resource planning for the California's load-serving utilities.

Data Collection

The paper incorporates power generation and fuel use data collected by the Energy Commission under the authority of the California Code of Regulations, Title 20, Division 2, Chapter 3, Section 1304(a) (1)-(2).[2] Under the regulations, commonly referred to as *QFER*, or Quarterly Fuel and Energy Reports, all owners of power plants with a nameplate capacity of 1 megawatt (MW) or more directly serving California end users must report their respective generation, fuel, and water usage for each calendar year. *Nameplate capacity* is defined as the maximum rated output of a generator under specific conditions as designated by the manufacturer. The Energy Commission compiles and posts the power plant data on its website.[3]

The reporting regulations also apply to a small number of out-of-state power plants that are electrically within a California balancing authority's control area and are considered to be directly serving California end users.[4] A *balancing authority* is responsible for controlling the generation and transmission of electricity within its control area and between neighboring balancing authorities through imports and exports of power. These out-of-state

1 *Funk & Wagnalls Standard College Dictionary*. 1976. Canadian ed. Toronto: Fitzhenry and Whiteside.

2 The reporting requirement became effective on February 23, 2001, following California's major electricity restructuring in 1996.

3 California Energy Commission website. QFER CEC-1304 Power Plant Owner Reporting Database. Accessed September 4, 2018. See http://www.energy.ca.gov/almanac/electricity_data/web_qfer/.

4 Balancing authorities operating in California include the Balancing Authority of Northern California, Bonneville Power Administration-Transmission, California Independent System Operator, Imperial Irrigation District, Los Angeles Department of Water & Power, Nevada Power Company, PacifiCorp West, Turlock Irrigation District, and Western Area Lower Colorado.

power plants include the Desert Star Energy Center in Nevada and the La Rosita Power Project and Termoeléctrica De Mexicali in Mexico.

Data have been compiled based on attributes of the natural gas-fired generating units within each power plant, and units have been assigned to one of five categories. All data categories are mutually exclusive, and no unit is double-counted. As an example, the 876 megawatt (MW) Scattergood Generating Station in Los Angeles County consists of two conventional steam turbine (ST) units rated at 163 MW each, two peaking units rated at 107 MW each, and a 336 MW combined-cycle (CC) power block composed of a 217 MW combustion turbine (CT) and a 119 MW ST unit. In this paper, all three groups of units are categorized separately based on the respective operational and physical characteristics. Chapter 2 describes the power plant categories in detail.

Heat Rates

The thermal efficiency of a natural gas-fired electric generation plant is typically described by measuring the *heat rate*. The heat rate of a power plant expresses how much fuel is necessary (measured in British thermal units [Btu]) to produce one unit of electric energy (measured in kilowatt-hours [kWh]). The heat rates used throughout this paper are calculated in *higher heating value* terms. Heating value is a measure of heat from the complete combustion of fuel. The reference to *higher* heating value in the determination of the heat rate includes the latent heat of vaporization of the water in the combustion of natural gas. Heat rates can also be expressed in terms of a *lower heating value,* and this measurement would not include the latent heat from the vaporization of the water. The lower heating value is generally used when comparing different fuel types such as coal, gasoline, and natural gas, where the presence of water vapor in the combustion of the fuel is significantly different.

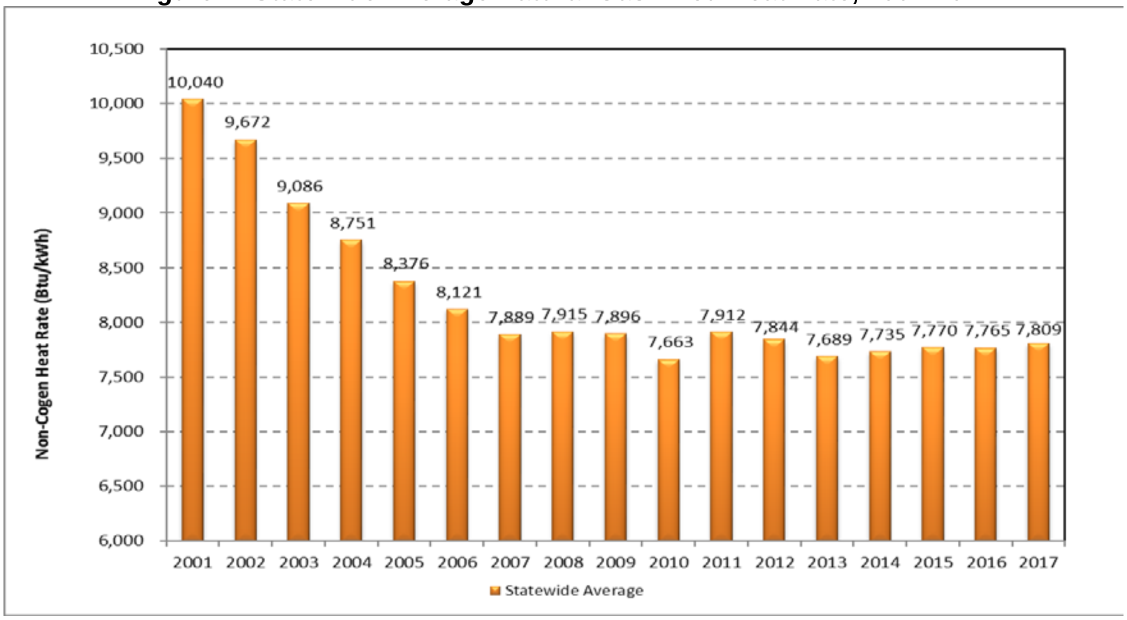
The heat rate of California's natural gas-fired generation fleet is obtained by the ratio of total annual fuel use to total annual electrical energy generated. A lower heat rate indicates a more efficient system as less fuel is used per kWh generated. **Figure 1** displays California's systemwide average heat rate over the past 17 years, excluding cogeneration.

Cogeneration plants are excluded from the systemwide average heat rate since these plants produce thermal energy simultaneously with electrical energy. The Energy Commission does not collect data on useful thermal energy from cogeneration plants. A heat rate calculation that accounted for the total system efficiency of cogeneration plants would result in a substantially lower effective heat rate than the simple calculation of fuel input versus electricity output indicates. There is, however, no industrywide standard for determining the heat rate for cogeneration systems. Two widely used methods differ on evaluating efficiency.[5] One method measures actual useful thermal output, while the other method measures the effective efficiency of a stand-alone steam boiler that would have been used if

5 U.S. EPA, *Methods for Calculating CHP Efficiency*, Retrieved on September 21, 2018, https://www.epa.gov/chp/methods-calculating-chp-efficiency.

the cogeneration system did not exist. The two approaches yield significantly different estimates of cogeneration efficiency. As such, the difficulty in assessing the efficiency gains related to the output of steam and useful heat is beyond the scope of this paper. This treatment is consistent with industry standards as exemplified in the United States Energy Information Administration's Form EIA-860, *Annual Electric Generator Report.*[6]

Figure 1: Statewide Average Natural Gas-Fired Heat Rate, 2001-2017



Source: QFER CEC-1304 Power Plant Data Reporting

From 2001 there is an almost steady reduction of the average heat rate through 2010 that coincides with the development of large, CC power plants in the state. The increased heat rate observed in 2011 was due to reduced operation of the gas fleet stemming from the large gains in available hydroelectric generation that year. In wet hydrological years, natural gas-fired generation is displaced (reduced) by low-cost hydroelectric generation. The magnitude of available hydroelectric generation in 2011 resulted in CC power plants operating at lower capacity factors, reducing overall efficiency.[7] Over the past five years, California has maintained an average heat rate of about 7,750 Btu/kWh, providing a thermal efficiency improvement of about 23 percent when compared to 2001.[8] The small increases in the systemwide average heat rate for 2014 through 2017 as shown in **Figure 1** are the result of natural gas-fired power plants adjusting their power output to accommodate fluctuations in available renewable generation within California's electrical grid.

6 U.S. EIA, Table 8.2. *Average Tested Heat Rates by Prime Mover and Energy Source, 2007–2013.* http://www.eia.gov/electricity/annual/html/epa_08_02.html.

7 The *capacity factor* is the ratio (expressed as a percentage) of the actual output of a power plant over a given period, to the related maximum potential output over the same period.

8 2014-2017 Average Heat Rate = 7,750 Btu/kWh. 2001 Average Heat Rate = 10,040 Btu/kWh. Percentage Change in Heat Rate = (10,040 – 7,754)/10,040 = 22.77 percent.

There are, however, practical limits to the state's ability to reduce its systemwide heat rate. The primary factor is related to how often the fleet of gas-fired power plants operate over their available hours. *Cycling* or *ramping* refers to gas plants altering output levels, including shutdowns and restarts, in response to changes in system load and the availability of renewable generation on the electrical grid. Cycling results in increased fuel consumption during those periods when a plant is not operating at the highest efficiency level, a result of the large temperature and pressure changes that take place in plant equipment. For those power plants designed to operate most efficiently at constant output levels, cycling leads to greater wear and tear and reduced lifespan of the equipment, along with reduced thermal efficiency. Studies have found that cycling results in a 1 percent permanent degradation in the heat rate of a generating unit over four to five years.[9]

Other factors that limit or constrain California's ability to reach higher thermal efficiency levels include topography and climate. Power plant efficiency is impacted by the location, elevation, and ambient weather conditions at each plant site. Locational factors may include emissions limits by air quality management districts, localized noise limits, and limits on hours of operation.[10] Power plants located in higher elevations experience reduced air density; lower air density decreases power generated by the gas turbine. Ambient weather also has a significant impact on thermal efficiency. Similar to high altitude factors, power plants located in areas with high average temperatures also experience reduced air density with a consequential loss in power generation efficiency.

Despite the slight increase in the average heat rate in recent years, California continues to benefit from an overall lower heat rate due in large part to its policy to retire less-efficient, once-through-cooling (OTC) power plants. In OTC, power plants draw water from the ocean or other large body of water to cool steam after it has passed through a turbine to create power. But the process results in the yearly loss of billions of aquatic organisms.[11]

On May 4, 2010, the State Water Resources Control Board (SWRCB) adopted a policy on the use of coastal and estuarine waters for power plant cooling to reduce the harmful effects on marine life. Of the 19 power plants originally identified in 2007, including California's two operational nuclear generating plants, all have planned to retire or have already retired by the mandatory deadlines established by the SWRCB. Recent OTC retirements include Mandalay Generating Station in Ventura County, Moss Landing Power Plant in Monterey County, Pittsburg Generating Station in Contra Costa County, Broadway Power Plant in Los Angeles County, and a portion of the Encina Power Station in San Diego County.

---

9 N. Kumar, P. Besuner, S. Lefton, D. Agan, and D. Hilleman. National Renewable Energy Laboratory. July 2012. *Power Plant Cycling Costs.* https://www.nrel.gov/docs/fy12osti/55433.pdf.

10 South Coast Air Quality Management District, *Rule 2012 – Requirements for Monitoring, Reporting, and Recordkeeping for Oxides of Nitrogen (NOx) Emissions.* http://www.aqmd.gov/docs/default-source/rule-book/reg-xx/rule-2012.pdf.

11 California Energy Commission Official Blog. Phase Out Looms for Power Plants That Use Water for Cooling. May 17, 2017. Accessed October 2, 2018. See http://calenergycommission.blogspot.com/2017/05/phase-out-looms-for-power-plants-that.html.

Accordingly, annual power generation from aging gas-fired power plants was down 50 percent from 2015 and 96 percent from 2001.

Table 1 details the annual average heat rate for each category of natural gas-fired power plants in California. The heat rates are based on the effective nameplate capacity of each generating unit as they operated over each year. The statewide average calculations are also based on individual generating unit operations. Each category has maintained a relatively consistent heat rate over the 17-year period, while the overall statewide average has fluctuated based on the annual power mix of the system.

Table 1: California Natural Gas-Fired Heat Rates, 2001–2017 (Btu/kWh)

	Combined-Cycle	Aging	Peaking	Cogeneration	Misc.	State Average	State Average w/o Cogen
2001	6,974	10,122	11,336	11,115	10,153	10,390	10,040
2002	7,147	10,529	10,866	11,097	9,530	10,301	9,672
2003	7,209	10,835	10,820	11,044	10,296	9,901	9,086
2004	7,178	10,917	10,804	11,302	9,957	9,705	8,751
2005	7,230	11,279	10,798	11,376	9,947	9,505	8,376
2006	7,229	11,282	10,762	11,307	9,975	9,129	8,121
2007	7,190	10,971	10,862	11,228	9,988	8,847	7,889
2008	7,147	11,131	10,582	11,472	10,074	8,869	7,915
2009	7,227	11,590	10,832	11,372	10,409	8,841	7,896
2010	7,199	11,677	11,014	11,175	9,923	8,665	7,663
2011	7,287	12,297	10,740	11,214	9,649	8,991	7,912
2012	7,231	11,702	10,858	11,247	9,564	8,631	7,844
2013	7,220	11,406	10,333	11,449	9,520	8,550	7,689
2014	7,295	11,775	10,309	11,445	9,327	8,552	7,735
2015	7,320	11,676	10,226	11,461	9,455	8,557	7,770
2016	7,339	12,311	10,263	11,621	9,403	8,683	7,765
2017	7,346	12,262	10,533	11,929	9,818	8,817	7,809

Source: QFER CEC-1304 Power Plant Data Reporting

Capacity Factors

The capacity factors shown in **Table 2** give an overview of how often California's fleet of natural gas-fired power plants operated each year. *Capacity factor* as used in this report is a measure of how often a group of power plants operate for a specific period. It is derived by comparing the net electricity generated to the energy that could have been generated at continuous operation at the total rated nameplate capacity for the group of plants during the same period. Reasons for power plants not operating at full capacity include planned and unplanned maintenance, high fuel costs relative to competing power plants, low system loads where power is not needed, and grid constraints.

The annual capacity factors in **Table 2** have been adjusted to account for midyear starts for newly operational plants based on the hours the unit was available in that initial year. For example, the 860 MW Delta Energy Center in Contra Costa County had an effective annual nameplate capacity of 577 MW for the first year of operation as it began commercial operation on May 1, 2002.

Table 2: California Natural Gas-Fired Power Plant Capacity Factors, 2001–2017

	Combined-Cycle	Aging	Peaking	Cogeneration	Misc.	State Average
2001	53.9%	42.2%	11.8%	68.0%	9.9%	44.9%
2002	65.7%	21.1%	5.3%	73.0%	9.7%	32.6%
2003	53.5%	15.3%	4.1%	71.2%	14.3%	30.1%
2004	58.6%	16.0%	4.4%	71.8%	15.4%	33.2%
2005	53.6%	10.0%	4.0%	66.2%	17.7%	30.0%
2006	53.8%	9.6%	3.7%	62.8%	16.6%	30.9%
2007	62.6%	9.1%	4.2%	64.4%	18.9%	34.3%
2008	62.4%	10.5%	4.4%	63.1%	19.9%	34.7%
2009	58.5%	7.7%	4.0%	61.1%	15.8%	32.2%
2010	52.2%	4.2%	3.0%	59.4%	18.1%	28.8%
2011	37.5%	4.1%	3.5%	58.9%	23.3%	24.1%
2012	55.3%	7.6%	5.1%	57.0%	21.1%	32.2%
2013	53.0%	5.5%	5.2%	56.1%	24.6%	30.2%
2014	52.0%	5.1%	5.8%	54.9%	24.3%	30.3%
2015	50.7%	5.6%	5.9%	51.9%	25.0%	30.1%
2016	40.7%	3.9%	5.1%	48.7%	23.2%	25.7%
2017	35.9%	4.2%	5.2%	45.6%	23.3%	24.4%

Source: QFER CEC-1304 Power Plant Data Reporting

The statewide average capacity factor for gas-fired generation dropped from 25.7 percent to 24.4 percent in 2017 due in part to the relatively slow retirement of aging generating capacity and the growth in peaking capacity over the past 10 years. Strong hydroelectric generation combined with significant solar and wind generation in 2017 reduced output from CC power plants to 35.9 percent, the lowest annual average of the past 17 years.

While California's CC plants have effectively replaced the contribution of energy from aging power plants, until the aging plants are permanently retired, the total operational capacity of aging power plants still impacts the annual average capacity factor. Aging plants continued to operate at extremely low capacity factors in 2017, 4.2 percent, a trend since 2010 that coincides with the implementation of the SWRCB's OTC policy. Peaking gas plants operated at the expected average capacity factor of about 5 percent. The Miscellaneous category comprises 17 power plants that are primarily internal combustion generators or repurposed CC plants that are not as efficient as the modern, purpose-built CC plants. In 2017, total capacity was 840 MW for the Miscellaneous category. Variations in capacity factor are due to the relatively small sample size. California's cogeneration plants operated at a 45.6 percent capacity factor in 2017, down 3 percent from 2016. These plants are operated at relatively high and consistent capacity factors due to the unique aspect of delivering both useful steam and electricity to the dedicated hosts. **Table 3** summarizes the effective nameplate capacity that was operational in each year for the five categories of natural gas-fired power plants.

Table 3: Effective Nameplate Capacity, 2001–2017 (MW)

	Combined-Cycle	Aging	Peaking	Cogeneration	Misc.	State Total*
2001	578	19,757	1,700	6,363	1,180	29,577
2002	2,251	19,794	2,819	6,401	1,191	32,456
2003	5,614	19,284	3,222	6,302	1,448	35,871
2004	7,304	17,690	3,393	6,242	1,522	36,150
2005	9,060	16,706	3,472	6,300	1,386	36,925
2006	12,190	16,866	3,697	6,276	1,266	40,295
2007	13,014	16,696	3,973	6,295	1,266	41,244
2008	13,848	16,621	4,724	6,280	1,099	42,571
2009	14,712	16,621	5,088	6,273	1,095	43,788
2010	15857	16,721	5,423	6,279	1,083	45,363
2011	16,663	15,924	5,661	6,078	1,228	45,555
2012	17,506	15,656	5,800	6,035	1,262	46,258
2013	18,781	15,656	7,796	6,055	833	49,121
2014	19,546	13,956	8,695	5,964	834	48.994
2015	19,570	13,044	8,667	5,939	839	48,058
2016	19,896	11,485	8,863	5,892	838	46,975
2017	19,896	8,636	9,169	5,810	840	44,351

Source: QFER CEC-1304 Power Plant Data Reporting (*Note: Figures may not sum due to rounding.)

CHAPTER 2: Natural Gas-Fired Power Plant Types

The natural gas-fired power plants examined in this paper are grouped into five categories based on a combination of duty cycles, vintage of the generating unit, and technology type. The five categories are Combined Cycle, Aging, Peaking, Cogeneration, and Miscellaneous. A detailed listing of the data set is published on the Energy Commission's website.[12]

Combined-Cycle Plants

Combined-cycle power plants comprise the next category. A CC power plant has a generation block consisting of at least one CT, a heat recovery steam generator (HRSG), and an ST. The higher fuel efficiency results from the ability of the HRSG to capture exhaust gas from the CTs to produce steam for the ST, often augmented with duct burning of natural gas within the HRSG. For this report, CC power plants consist of those natural gas-fired generating blocks constructed in the 2000s with a total plant capacity of 100 MW or more.

In 2001, the 550 MW Sutter Energy Center in Yuba City (Sutter County) and the 594 MW Los Medanos Energy Center in Pittsburg (Contra Costa County) were the only CC power plants with this new technology; by 2017, California had 35 large CC plants totaling almost 20,000 MW in nameplate capacity. These newer plants produce electricity with better heat rates than either stand-alone CTs or STs. Historically, these plants have been used as baseload generation. *Baseload generation* refers to those plants that are designed to operate at an annualized capacity factor of at least 60 percent. However, with the increasing integration of renewable generation along with the inherent regulatory must-take generation from cogeneration facilities and QFs, CC plants are increasingly being tasked for flexible, load-balancing requirements that involve more frequent cycling and load-following ancillary services.[13]

Load-following ancillary services are reserved electric generating capacity that can be increased or decreased through automatic generation control systems to allow continuous balance between generating resources and electricity demand. Load following is understood as the difference in generation requirements between the hour-ahead energy forecast and the five-minute-ahead forecast within a balancing authority, such as the California Independent System Operator (California ISO).[14] Deficiencies between the hour-ahead and five-minute-ahead forecasts are met by adjusting the output of power plants via load following to ease sudden

12 California Energy Commission website. QFER CEC-1304 Power Plant Owner Reporting Database. Accessed July 20, 2018. See http://www.energy.ca.gov/almanac/electricity_data/web_qfer/.

13 Must-take generating resources are identified by the California ISO or a local regulatory authority as generating units that are subject to an existing QF contract or a power purchase agreement with mandatory obligations under federal law. Must-take generation also includes generation from nuclear units and generation delivered from cogeneration plants with mandatory requiremens to serve a thermal host.

14 Makarov, Yuri V., Clyde Loutan, Jian Ma, and Phillip de Mello. 2009. *Operational Impacts of Wind Generation on California Power Systems*. See http://www.caiso.com/Documents/OperationalImpacts-WindGenerationonCaliforniaPowerSystems.pdf.

changes within the grid, such as a loss of load or the integration of variable solar and wind renewable energy.

Aging and Once-Through-Cooling Plants

The Aging category includes plants built and operational before 1980. Almost all are natural gas-fired STs that use OTC technology. Due to environmental concerns, a statewide OTC policy was adopted in 2010 requiring all owners of OTC plants to implement a best available control technology to achieve water quality goals, specifically, a closed-cycle evaporative cooling system. Two compliance tracks were established to meet the new OTC policy, which involved reducing intake flows to levels that can use closed-cycle evaporative cooling. Alternatively, a plant could comply by shutting down.[15] The majority of plants have a compliance date of December 31, 2020, while a few have compliances dates of December 31, 2024 and 2029.

In 2001, prior to implementation of the SWRCB's OTC policy, there were 27 aging natural gas-fired power plants with an operational nameplate capacity of almost 20,000 MW. Seventeen of the 27 aging plants were classified as OTC, reflecting 15,134 MW in total nameplate capacity. By the close of 2017, a dozen aging power plants remained, accounting for 8,529 MW of capacity. Eight of these aging plants are also classified as OTC with a total capacity of 7,434 MW. Most recently, on February 6, 2018, NRG's 573 MW Mandalay Generating Station retired after more than 60 years of operation.

Located in Oxnard in Ventura County, the Mandalay Generating Station had two conventional steam units that drew water from Channel Islands Harbor as part of the OTC operation. These two units are included within the aging dataset of this report. Originally brought on-line in 1956 and 1959, the two 217 MW steam units remained in operation through December 2017. Mandalay also had a 138 MW peaking unit that operated throughout 2017. As the peaking unit did not require the use of cooling water, it was not classified as an OTC unit. The peaking unit was not included in the aging dataset due the its duty cycle. Rather, it is included in the following dataset on peaking power plants.

Peaking Plants

The Peaking category consists of simple-cycle generating units. These units have a peaking duty cycle role—specifically, they are called upon to meet peak demand loads for a few hours or less on short notice, often in the 15-minute or 5-minute-ahead real-time market. This category also includes two newly integrated battery energy storage systems (BESS) installed at the Grapeland Peaker Plant in Rancho Cucamonga (San Bernardino County) and the Center Peaker Plant in Norwalk (Los Angeles County). The new technology features a 10 MW, 4.3 MWh BESS that allows the peaking plant to provide instantaneous energy to the grid, thereby avoiding fuel use from the gas turbine operating at minimum loads.

---

15 California Energy Commission. Tracking Progress. *Once-Through Cooling Phase Out.* http://www.energy.ca.gov/renewables/tracking_progress/documents/once_through_cooling.pdf.

Traditionally, peaking plants have provided *nonspinning reserves*, a term denoting non-operating plants capable of ramping up to full capacity and synchronizing to the grid within 10 minutes of dispatch. However, with the new BESS hybrid configurations, these plants can now provide spinning reserves without operating the gas turbine. *Spinning reserves* is a term referencing operating (in other words, spinning) resources that are synchronized and ready to meet electric demand within 10 minutes through ramping to maintain system stability. The BESS provides instantaneous ramping to accomodate renewable integration and results in fewer starts for the gas turbine, reduced water usage, and reduced emissions. Both greenhouse gas (GHG) and criteria pollutant emissions are reduced as the BESS allows the turbine to operate at more efficient, full load output levels more often and reduces the times when then turbine operates at partial load.

In 2001, there were 29 peaking plants in California; by 2017, there were 76 facilities with 9,169 MW of nameplate capacity. This number is down slightly from 78 facilities in 2016 after the retirements of the El Cajon Plant (13 MW) and the Miramar Plant (33 MW), both located in San Diego County.

Cogeneration Plants

The Cogeneration category consists of a mix of CCs, CTs, and STs. These plants, commonly referred to as *combined heat and power*, produce heat and electricity for onsite usage or a nearby dedicated thermal or electric host, such as a petroleum refinery or college campus, or direct supply to the electrical grid. Cogeneration plants are often classified as qualifying facilities, or QFs, as defined under the Code of Federal Regulations Public Utility Regulatory Policies Act of 1978 (PURPA).[16] PURPA was intended to foster innovation in renewable generation and level competition with traditional fossil fuel generation for small power producers.

QFs fall into two categories: qualifying small power production facilities of 80 MW or less whose primary energy source is renewable, biomass, waste, or geothermal resources and qualifying cogeneration facilities. There is no size limitation for qualifying cogeneration facilities. The primary benefit of being classified as a QF is the ability to sell power to utilities at avoided cost rates. *Avoided cost rates* are defined as the rate that would approximate the cost for a utility to generate or purchase the same amount of electricity from another source.

Traditionally, utilities were able to purchase nonutility electricity at rates below their own generation costs, and this put small power producers and cogenerators at a disadvantage. Since cogenerators serve dedicated thermal hosts, they do not have the same flexibility as traditional power plants to curtail their electric generation without also affecting their thermal operations. By attaining QF status under PURPA, cogenerators are guaranteed to be able to sell their power to a local utility. Over the years since the PURPA regulations took effect, utilities have tried to limit the definition of a cogeneration plant due in part to the high fixed costs associated with interconnecting to cogeneration facilities. However, federal courts have consistently maintained

16 Qualifying facilities as defined in 16 U.S.C. §796(18)(A) and 18 CFR 292.203.

a broad interpretation on the definition of cogeneration and what constitutes a QF facility. The PURPA regulations have resulted in qualifying cogeneration facilities operating at consistently high capacity factors over the past 17 years of QFER data.

The number of cogeneration plants in California is slowly declining, from 151 operational plants in 2001 to 126 plants at the end of 2017. Total capacity for cogeneration plants in 2017 is 5,678 MW, down 702 MW from 2001. Two-thirds of the plants are rated at 50 MW or less with a median capacity of 28 MW.

Miscellaneous Plants

All remaining natural gas-fired power plants are included in the Miscellaneous category. These include technologies such as fuel cell and reciprocating engine applications, turbine testing facilities, as well as older generating units built before the 2000s that are not considered to be aging, peaking, or cogeneration. This category also includes generating units that have been repowered from stand-alone CT or ST operation to CC operation such as the El Centro Unit 2 in the Imperial Irrigation District.

Imperial's El Centro Unit 2 was originally commissioned in 1952 as a natural gas and residual fuel oil steam boiler unit with a nameplate capacity of 32 MW. In 1992, the plant was repowered by upgrading the existing ST and adding a new CT along with a HRSG, bringing the total nameplate capacity to 124 MW. High ambient temperatures and dusty conditions at the plant site combined with a slightly reduced designed-output level to ease maintenance limited the power plant in reaching the originally planned for 8,400 Btu/kWh heat rate. It operates with an annual average heat rate of 9,425 Btu/kWh at a 37 percent annual capacity factor.

CHAPTER 3:
Natural Gas-Fired Generation

California has more than 44,000 MW of installed gas-fired generation capacity, as detailed in **Table 4**. However, with an annual average capacity factor of only 24.4 percent, much of the state's gas-fired capacity is sitting idle most of the time. The cleanest burning combined-cycle plants provided two-thirds of the total gas-fired generation in 2017, with cogeneration providing an additional 25 percent. Aging, peaking, and miscellaneous plants accounted for less than 10 percent in total. As suggested by the low capacity factor, California's gas-fired generation was displaced by generation from non-GHG-emitting electric generation categories (large hydroelectric, nuclear, and renewables) that accounted for more than 56 percent of total in-state generation in 2017.

Table 4: California Natural Gas-Fired Power Plant Summary Statistics, 2017

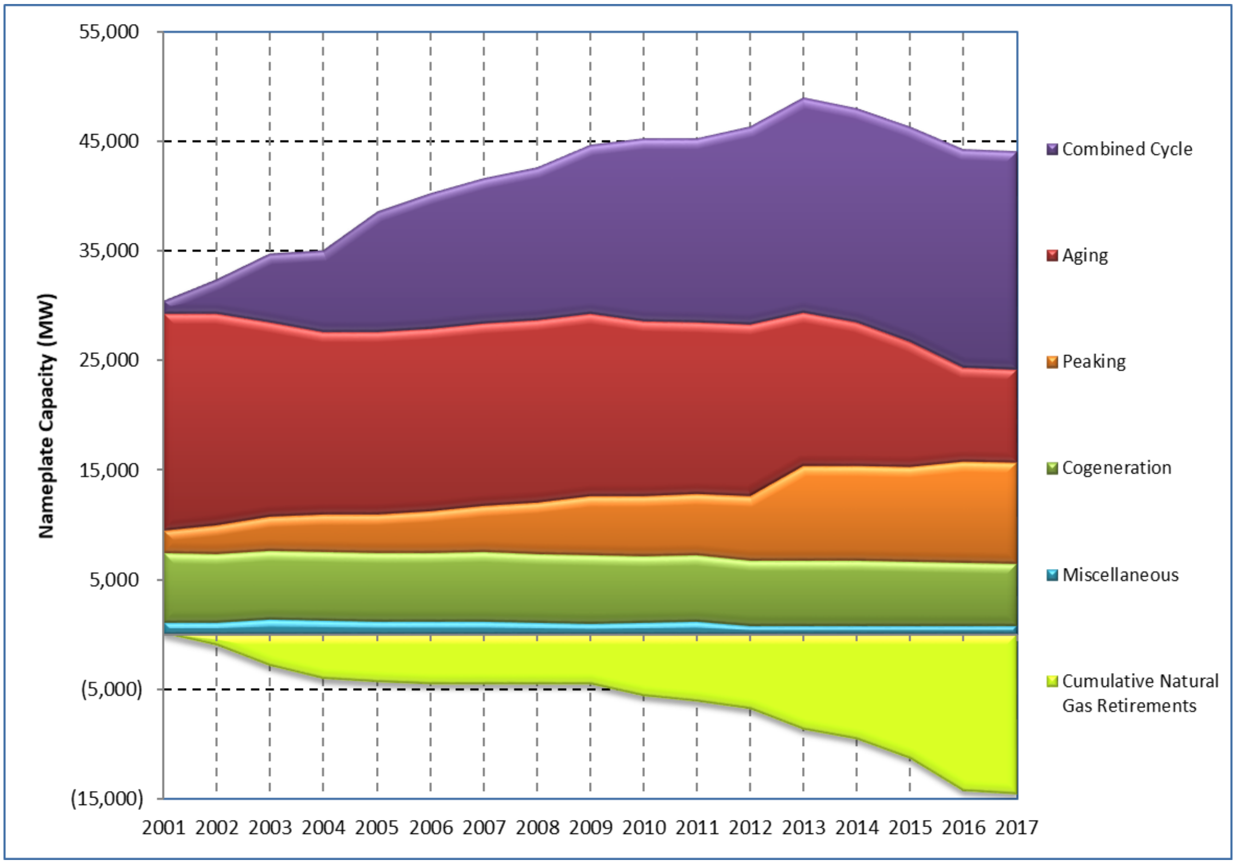
Category	Capacity (MW)	Share of Capacity	Energy (GWh)	Share of Energy	Capacity Factor	Heat Rate (Btu/KWh)
State Total (All Types)	44,112	100.0%	94,954	100.0%	24.4%	8,817
State Total (w/o Cogeneration)	38,434	N/A	71,674	N/A	21.4%	7,809
Combined-Cycle	19,896	45.4%	62,750	66.1%	35.9%	7,346
Aging	8,529	19.5%	3,183	3.4%	4.2%	12,262
Peaking	9,169	20.2%	4,033	4.2%	5.2%	10,533
Cogeneration	5,678	13.0%	23,280	24.5%	45.6%	11,929
Miscellaneous	840	1.9%	1,708	1.8%	23.3%	9,818

Source: QFER CEC-1304 Power Plant Data Reporting

Capacity Trends

Figure 2 displays the changes in capacity that have taken place in each category over the past 17 years. Natural gas-fired generation that has been retired since 2001 is shown by the blue area under the stacked-area graph. Peaking and CC categories have expanded in capacity, while aging and cogeneration plants have slowly but steadily retired over the years. Cumulatively, more than 14,500 MW of capacity has retired since 2001.

Figure 2: Annual Natural Gas-Fired Capacity by Plant Category, 2001-2017

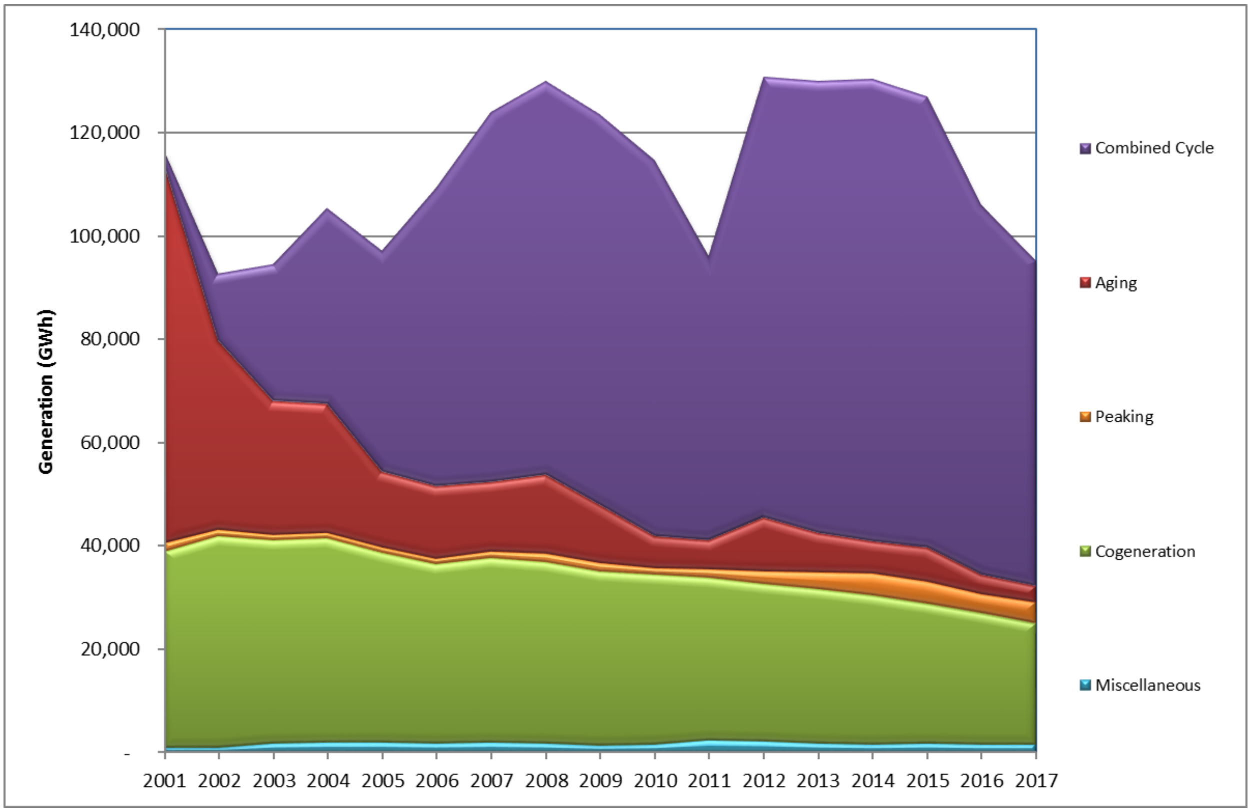


Source: QFER CEC-1304 Power Plant Data Reporting

Generation Trends

The annual mix of electric generation from five categories of gas-fired power plants is shown in **Figure 3**. Compared to the capacity changes shown in **Figure 2**, the current energy mix highlights the dramatically diminished role aging plants now play in California. The large fluctuations in output from CC plants stem from the availability of hydroelectric generation in a given year. The drought years of 2012 through 2015 saw heavy usage of gas-fired generation, with more than 120,000 gigawatt-hours (GWh) each year. The steep drops in output observed in 2011, 2016, and 2017 were the result of an abundance of available hydroelectric energy during those relatively wet hydrological years. This past year also has the distinction of having the lowest in-state gas-fired generation of the past 17 years, down to 89,824 GWh. With an additional 5,130 GWh delivered from the three gas-fired plants in Nevada and Mexico that exclusively serve California end users, California's annual total of 94,954 GWh still ranks as the third lowest in the past 17 years. The low generation highlights the substantial growth of renewable energy and the periodic availability of hydroelectric generation.

Figure 3: Natural Gas-Fired Electric Generation in California, 2001-2017



Source: QFER CEC-1304 Power Plant Data Reporting

California's aging power plants accounted for about 3 percent (3,183 GWh) of gas-fired electric generation in 2017 but still hold 19.5 percent of the state's gas-fired generation capacity, nominally rated at 8,529 MW. With an average heat rate of 12,262 Btu/kWh, California's aging plants continue to carry the distinction of having the most inefficient heat rates. The low capacity factors suggest the primary value of this group of power plants is in providing capacity support for local reliability that may include voltage control, frequency control, and other ancillary services.[17] Control of voltage and frequency within a power system are essential to maintaining the balance between generation and load.

Voltage control in an alternating current power system is defined as the ability to adjust for changes in *reactive power*. Reactive power supports the magnetic and electric fields required for alternating current power systems to function. As reactive power does not travel as far as real power, power plants within a control area are required to control voltage by generating or consuming reactive power. *Frequency control* is defined as the ability to dispatch generation due to decreases in supply or increases in load within a power system.

Statewide capacity of the CC plants account for 45 percent of California's total natural gas-fired generation capacity. In 2017, they provided 66 percent (62,750 GWh) of the total gas-fired

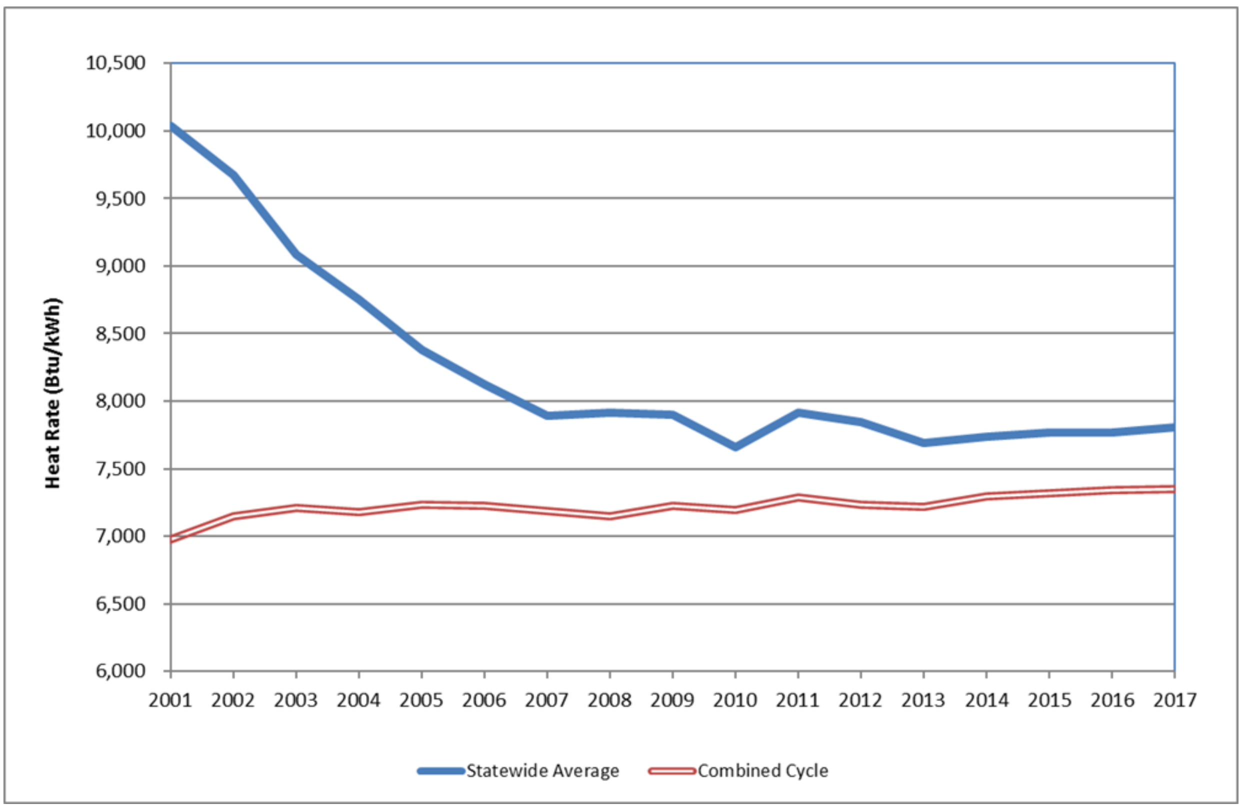
---

17 California Energy Commission. *The Role of Aging and Once-Through-Cooling Power Plants in California—An Update.* CEC-200-2009-018. See http://www.energy.ca.gov/2009publications/CEC-200-2009-018/CEC-200-2009-018.PDF.

energy. CC plants operated at an average capacity factor of 35.9 percent and had an average heat rate of 7,346 Btu/kWh. The impact from the large growth in CC plants has been to reduce reliance upon the state's fleet of aging power plants, now operating at a minimal 4 percent capacity factor.

Figure 4 shows how the average heat rate for natural gas-fired generation in California has improved over the majority of the past 17 years and compares this to the average heat rate for California's CC plants. These gains in power plant efficiency are cumulative and result in direct reductions in greenhouse gases (GHGs) as the heat rate is directly proportional to GHG emissions. The greatest efficiency gains occurred from 2001 through 2010, a period when the majority of CC plants began commercial operation. In 2011, the displacement of natural gas-fired generation by hydroelectric power resulted in a higher heat rate that year. In 2017, hydroelectric generation in California reached 43,347 GWh, 50 percent higher than 2016's level of 28,986 GWh and more than three times 2015's level of 13,996 GWh. The displacement of gas-fired generation by hydroelectric generation was a primary factor in the recent increases in the average heat rate.

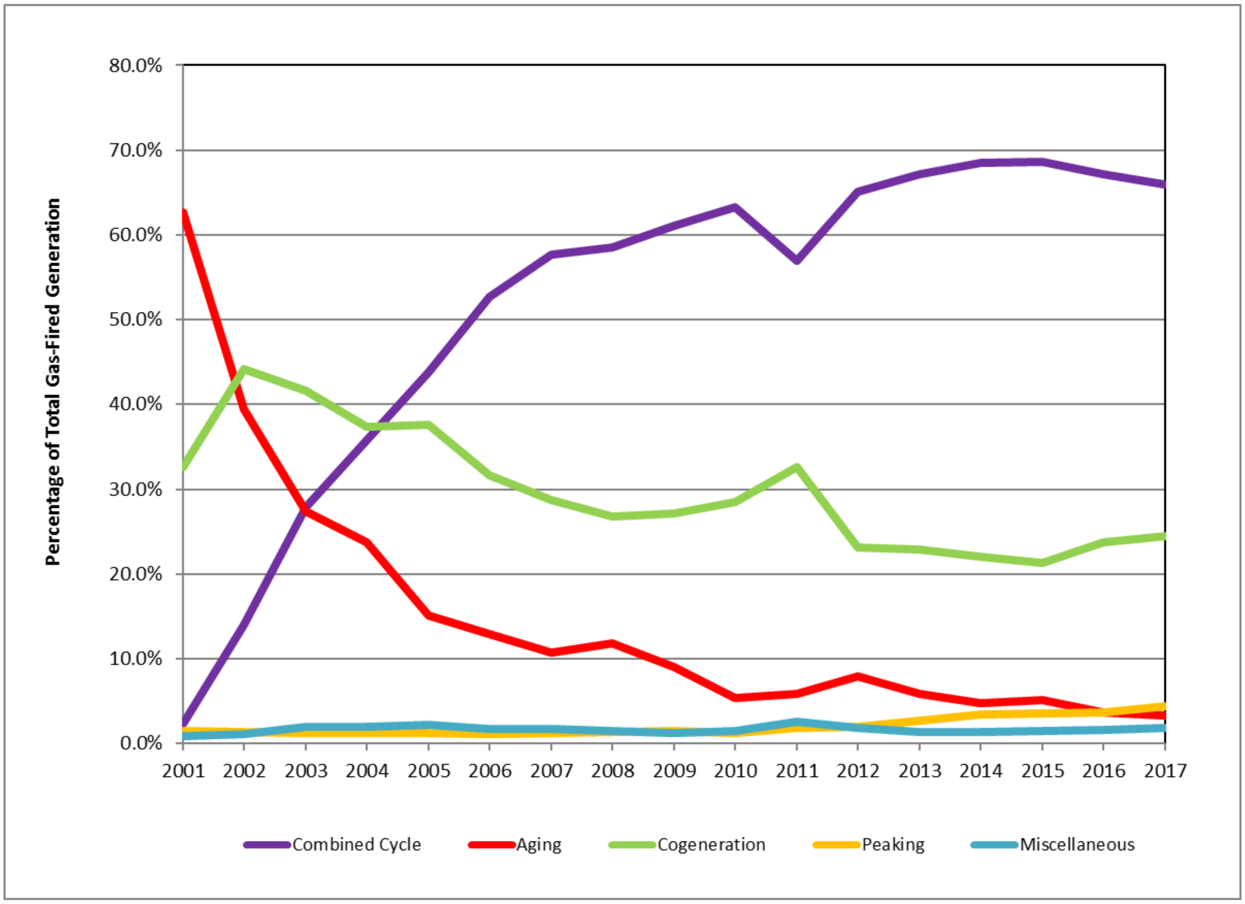
Figure 4: Combined-Cycle Heat Rate Compared to Statewide Average, 2001-2017



Source: QFER CEC-1304 Power Plant Data Reporting

Figure 5 illustrates how the share of energy from CC plants has become the dominant form of gas-fired generation in the years following 2003. In 2001, aging power plants generated 63 percent (73,000 GWh) of the total energy from natural gas, while CC plants generated only 2 percent (2,730 GWh). By 2017, CC plants generated 66 percent (62,750 GWh), while aging plants accounted for only 3 percent (3,183 GWh). The total capacity of California's CC plants (19,896 MW) is now virtually identical to the total capacity of California's aging plants in 2001.

Figure 5: Share of Total Natural Gas-Fired Generation by Plant Type, 2001-2017



Source: QFER CEC-1304 Power Plant Data Reporting

Table 5 and **Table 6** provide the annual generation and fuel use for each natural gas-fired power plant category over the past 17 years. Aging plants steadily decreased in output over the past 17 years with the exception of 2012, when they were called upon to generate because of the unplanned early retirement of the San Onofre Nuclear Generating Stations. Peaking power plants have increased output in recent years to promote renewable integration, and the category surpassed total aging generation in 2017. With a lower average heat rate than aging plants, peaking plants have also helped improve the overall thermal efficiency of the system. The efficiency improvement resulting from California's changeover from aging to CC power plants has provided a direct reduction in GHG emissions from what would have been the case if CC power plants had not been introduced to the power mix.

Table 5: Generation From California's Natural Gas-Fired Power Plants, 2001–2017 (GWh)

	Combined-Cycle	Aging	Cogeneration	Peaking	Miscellaneous	State Total
2001	2,730	73,000	37,898	1,752	1,024	116,404
2002	12,954	36,526	40,923	1,317	1,013	92,733
2003	26,335	25,877	39,329	1,145	1,809	94,496
2004	37,605	24,937	39,358	1,304	2,064	105,268
2005	42,576	14,639	36,559	1,206	2,145	97,125
2006	57,481	14,132	34,552	1,214	1,840	109,219
2007	71,357	13,339	35,500	1,471	2,099	123,766
2008	75,936	15,303	34,824	1,840	1,919	129,823
2009	75,382	11,193	33,559	1,796	1,513	123,443
2010	72,472	6,216	32,660	1,436	1,714	114,498
2011	54,748	5,679	31,372	1,757	2,472	96,028
2012	85,090	10,421	30,231	2,615	2,307	130,663
2013	87,179	7,586	29,751	3,554	1,775	129,846
2014	89,112	6,221	28,675	4,388	1,752	130,147
2015	86,990	6,448	27,022	4,444	1,822	126,725
2016	71,158	3,892	25,197	3,898	1,694	105,839
2017	62,750	3,183	23,280	4,033	1,708	94,954

Source: QFER CEC-1304 Power Plant Data Reporting

Table 6: Natural Gas Usage for California's Power Plants, 2001–2017 (Thousand MMBtu)

	Combined-Cycle	Aging	Cogeneration	Peaking	Miscellaneous	State Total
2001	19,036	738,925	421,238	19,862	10,396	1,209,457
2002	92,581	384,568	454,126	14,307	9,658	955,239
2003	189,850	280,369	434,340	12,386	18,627	935,571
2004	269,908	272,229	444,807	14,090	20,554	1,021,589
2005	307,828	165,110	415,910	13,021	21,335	923,204
2006	415,525	159,434	390,662	13,067	18,350	997,038
2007	513,084	146,343	398,607	15,977	20,965	1,094,975
2008	542,740	170,334	399,514	19,473	19,338	1,151,399
2009	544,781	129,731	381,631	19,453	15,754	1,091,350
2010	521,691	72,587	364,983	15,816	17,007	992,084
2011	398,968	69,827	351,808	18,869	23,732	863,205
2012	615,296	121,944	340,024	28,393	21,947	1,127,604
2013	629,434	86,530	340,613	36,726	16,820	1,110,124
2014	650,038	73,245	328,189	45,231	16,272	1,112,974
2015	636,741	75,279	309,691	45,442	17,155	1,084,309
2016	522,255	47,919	292,818	40,027	15,889	918,909
2017	460,969	39,026	277,702	42,558	16,752	837,008

Source: QFER CEC-1304 Power Plant Data Reporting

CHAPTER 4: Total System Electric Generation

Total system electric generation is a method of accounting for the complete fuel source profile of California each year, as shown below in **Table 7**.

Table 7: California's Total System Electric Generation for 2017

Fuel Type	California Generation (GWh)	Percent of California Generation	Northwest Imports (GWh)	Southwest Imports (GWh)	California Energy Mix (GWh)	California Power Mix
Coal	302	0.15%	409	11,364	12,075	4.13%
Large Hydro	36,920	17.89%	4,531	1,536	42,987	14.72%
Natural Gas	89,564	43.40%	46	8,705	98,315	33.67%
Nuclear	17,925	8.69%	0	8,594	26,519	9.08%
Oil	33	0.02%	0	0	33	0.01%
Other	409	0.20%	0	0	409	0.14%
Renewables	61,183	29.65%	12,502	10,999	84,684	29.00%
Biomass	*5,827*	*2.82%*	*1,015*	*32*	*6,874*	*2.35%*
Geothermal	*11,745*	*5.69%*	*23*	*937*	*12,705*	*4.35%*
Small Hydro	*6,413*	*3.11%*	*1,449*	*5*	*7,867*	*2.70%*
Solar	*24,331*	*11.79%*	*0*	*5,465*	*29,796*	*10.20%*
Wind	*12,867*	*6.24%*	*10,015*	*4,560*	*27,442*	*9.40%*
Unspecified Energy	N/A	N/A	22,385	4,632	27,017	9.25%
Total	206,336	100.00%	39,873	45,830	292,039	100.00%

Source: QFER CEC-1304 Power Plant Data Reporting and SB 1305 Power Source Disclosure Reporting

Table 7 also summarizes both in-state generation and net energy imports into California from neighboring states as well as Canada and Mexico. In 2017, total generation for California was

292,039 GWh, up 0.5 percent from 2016. Natural gas-fired generation fell by 7 percent to 98,315 GWh.

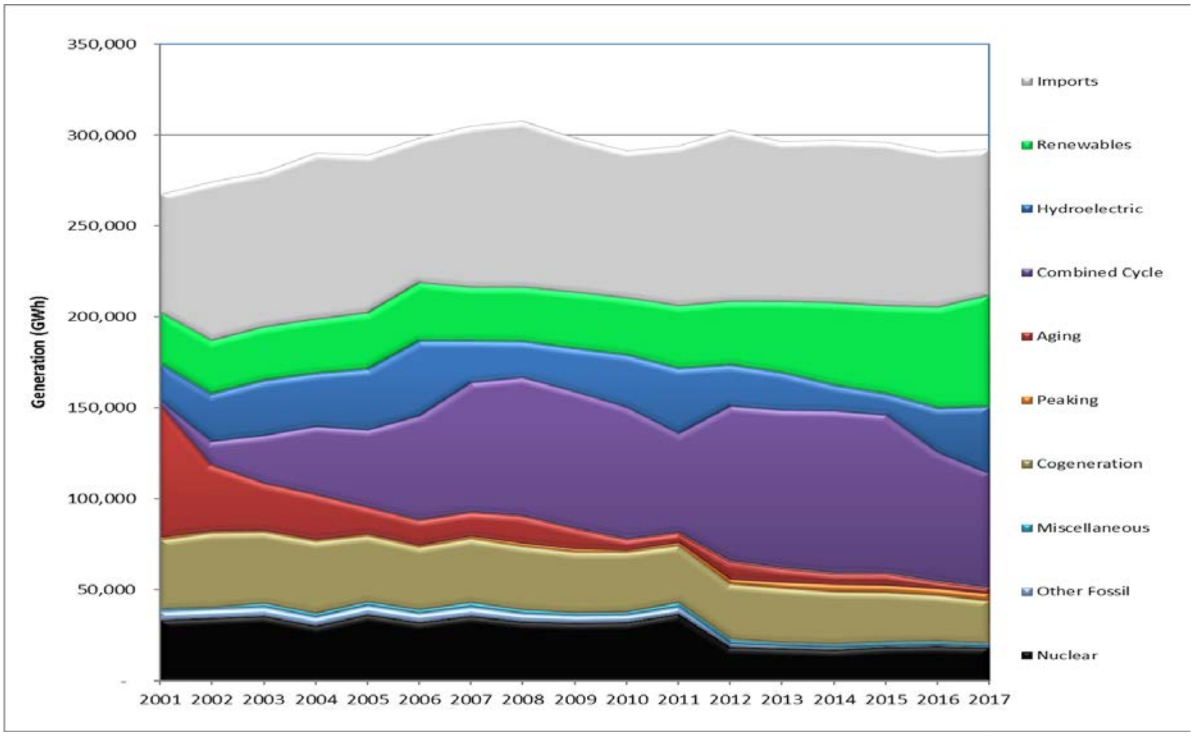
With the drought conditions of previous years coming to a close by the end of 2016, California started the year with its second wettest winter on record. By February 1, 2017, parts of California had snowpack levels of more than 180 percent of normal.[18] Accordingly, on April 7, 2017, Governor Edmund G. Brown Jr. declared an official end to California's four-year drought.[19] By the end of 2017, California's hydroelectric generation climbed to the highest level since 2006, increasing by 50 percent over 2016 to reach 43,333 GWh. Imported hydroelectric energy added another 7,521 GWh for the year, bringing the total to 50,854 GWh — about 17 percent of the total energy mix. As hydroelectric generation increased, California's gas-fired generation was similarly displaced, dropping to 89,564 GWh, the lowest level of the past 17 years.

To provide a visual context for the relative importance of California's gas-fired generation with respect to total system electric generation, **Figure 6** summarizes the energy contribution from each of the five natural gas-fired power plant categories together with all other fuel types serving California.

18 NOAA National Centers for Environmental Information, *State of the Climate: National Snow & Ice for February 2017,* published online March 2017, retrieved on May 30, 2018, from https://www.ncdc.noaa.gov/sotc/snow/201702.

19 Executive Order B-40-17, State of California, retrieved on August 6, 2018, from https://www.gov.ca.gov/docs/4.7.17_Exec_Order_B-40-17.pdf.

Figure 6: California's Total System Electric Generation, 2001-2017



Source: QFER CEC-1304 Power Plant Data Reporting

Imported energy, shown in gray, plays a large role in shaping the state's overall efficiency. California generates about two-thirds of its power from power plants within the state's borders while importing the remaining one-third from other western states, Canada, and Mexico. Imported energy is composed of both long-term contracts by California utilities with specifically identified power plants, referred to as *specific claims*, and short-term, spot-market purchases. For those short-term purchases that are not able to be traced back to the originating power plant, the purchase is considered to be *unspecified energy*. Unspecified energy can also include *null energy* — energy from a certified renewable facility that has been separated from its renewable attributes (Renewable Energy Credits, or RECs) and sold independently from the REC. In 2017, unspecified energy accounted for 32 percent of total imports and about 9 percent of California's total system requirements.

CHAPTER 5:
California ISO Balancing Area Generation

Annual Changes in Hourly Generation

The California ISO is one of nine balancing authorities operating in California and manages about 78 percent of the state's total electric service territory. The hourly operational differences between 2017 and 2016 for CC, aging, and peaking power plants within the California ISO are presented in **Table 8.** For each year, the fleet totals and plant averages were calculated using energy values greater than 10 MWh. Values less than or equal to 10 MWh were eliminated to avoid inclusion of partial hours of operation that tend to exaggerate the statistical differences in the calculation of standard deviation and the average.

Table 8: California ISO Gas-Fired Generation Summary, 2016-2017

Hours Generating > 10 MWh	Combined Cycle		Aging		Peaking	
	2016	2017	2016	2017	2016	2017
Fleet: Total Generation (MWh)	56,725,177	49,148,345	2,727,369	2,752,340	2,589,099	3,054,956
Plant: Avg. Hourly Output (MWh)	316	311	96	95	47	47
Plant: Std. Deviation (MWh)	173	172	98	105	30	34
Fleet: Operational Hours	179,654	158,208	28,487	29,083	54,656	65,315
Fleet: Total Available Hours	307,440	289,080	254,736	192,720	860,832	849,720
Number of Generating Units	35	33	29	22	98	97

Source: California ISO aggregated data

Combined-cycle plants within the California ISO operated at an average output of 311 MW in 55 percent of all available hours in 2017. The average hourly output of these plants is down 4 MW from 2016 to 311 MWh. Overall, total generation from CC plants within the California ISO declined by 13 percent to 49,148 GWh. The variability of hourly generation, as defined by the standard deviation, remained about the same at 172 MWh. Across almost 160,000 operational hours, 68 percent of the time the hourly output for CC plants ranged between 139 MWh and 483 MWh. For comparison, the range in output in 2016 was 143 MWh to 489 MWh, a change in range of less than 1 percent. Overall. CC plants within the California ISO balancing area operated very similarly across both years.

Aging plants within the California ISO generated almost the same amount of energy in 2017 as 2016, approximately 2,752 GWh, as shown in **Table 8**. The average hourly output was also similar across each year, 95 MWh in 2017 and 96 MWh in 2016. They operated slightly more often in 2017, about 4 percent more, taking into account that there were fewer aging units in operation. Seven aging units retired in 2017, reducing the total number of aging units to 22.

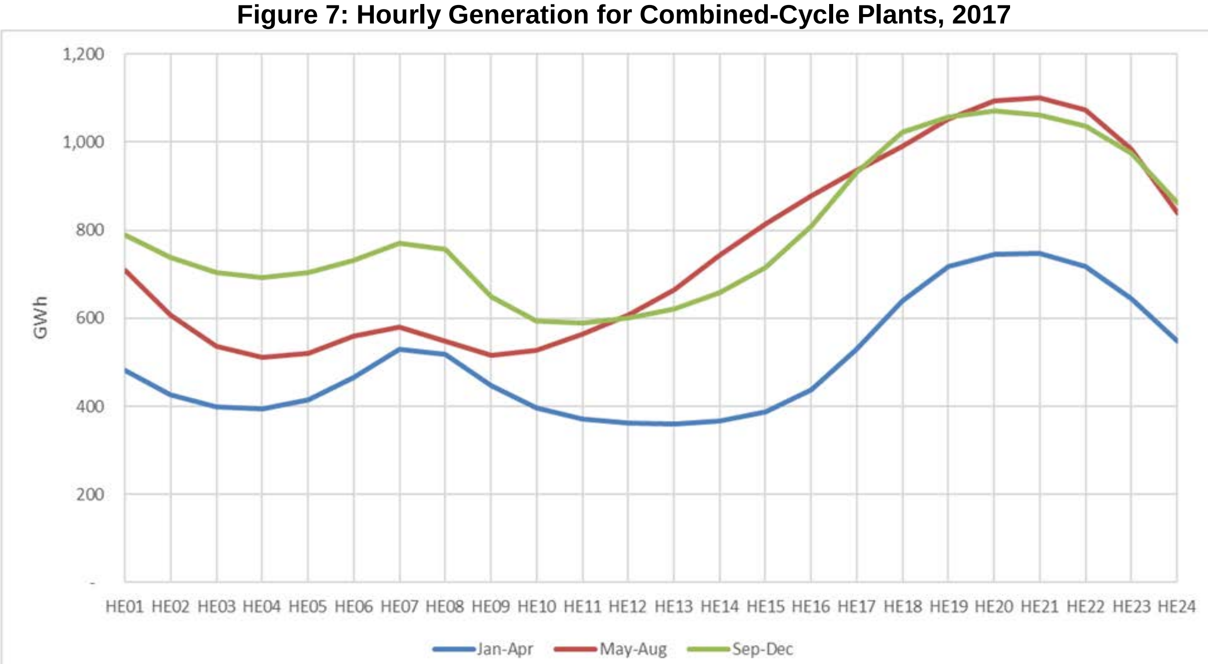
These changes also contributed to the 7 percent increase in variability in 2017, as measured by the standard deviation value of 105 MWh.

Providing slightly more energy than aging plants, peaking plants in the California ISO generated 3,055 GWh in 2017, up 18 percent from 2016. The average hourly output was unchanged at 47 MWh. The data also show that peaking plants increased variability about the mean by 13 percent in 2017. Peaking plants in the California ISO balancing area operated in almost 8 percent of all available hours, up slightly more than 1 percent compared to 2016. These changes in operation came about as the summer months in 2017, as measured from June through August, set a record as the warmest in 123 years of recorded temperatures in the state. Temperatures peaked on September 1st as a heat storm shattered temperature records across California. San Francisco, Oakland, San Jose, and Santa Cruz all experienced record-setting temperatures, as did many other cities throughout California.[20]

Hourly Generation Profiles

Figure 7 displays the annual generation provided by CC plants for each hour-long period across 2017. Generation in the summer months, defined as May 1 through August 31, shows a significantly flatter, almost linear, slope of increasing electric generation from 10:00 a.m. (HE10) through to 8:00 p.m. (HE20). The CC fleet, while being used across all hours of the day to support system load, steadily increases output across these hours to replace declining solar generation as the available daylight hours begin to wane after noon.

Figure 7: Hourly Generation for Combined-Cycle Plants, 2017



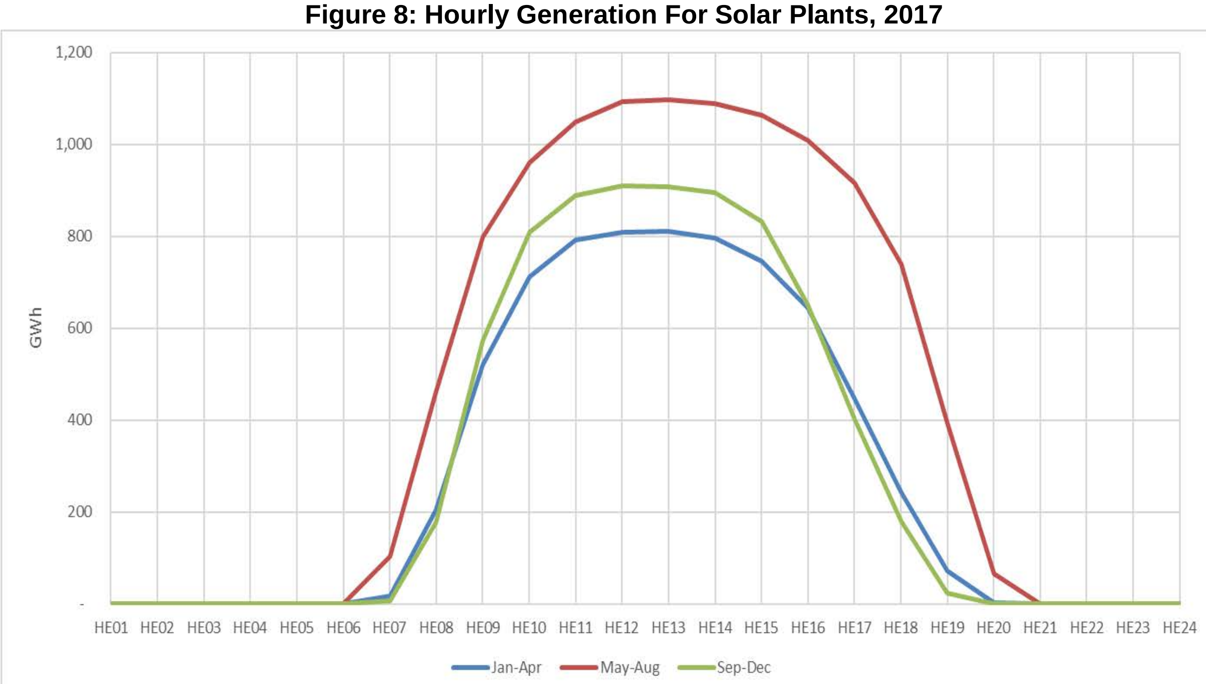
Source: California ISO aggregated data

20 National Weather Service Forecast Office, retrieved on September 18, 2018, from https://www.wrh.noaa.gov/climate/monthdisp.php?stn=KSFO&year=2017&mon=9&wfo=mtr.

From January 1 through April 30, electric generation from CC plants is reduced due to the availability of cheaper, hydroelectric generation. Hydroelectric generation can significantly displace gas-fired generation during periods of high snowpack levels in California's mountain ranges. From September 1 through December 31, hydroelectric generation is no longer as readily available to meet California's electric system load requirements as reservoirs restrict water releases to build up and maintain storage levels for water deliveries in the following spring and summer. Accordingly, CC plants are dispatched at higher output levels in the fall and early winter to make up for the reduced availability of hydroelectric generation.

CC plants are also dispatched to meet increasing loads in the early, predawn hours from 4:00 a.m. (HE04) through 8:00 a.m. (HE08) before the onset of solar generation. As solar generation ramps up after 7:00 a.m. (HE07), CC plants are dispatched at reduced levels of output until the later afternoon hours, where they then face a steeper ramp rate to meet the system peak. The ramping is steeper in the winter and spring, as there are fewer available daylight hours for solar generation and yet the maximum capacity of available solar generation is unchanged across all seasons. With the same four-month grouping as shown in **Figure 7**, California's solar generation profile is shown in **Figure 8**.

Figure 8: Hourly Generation For Solar Plants, 2017

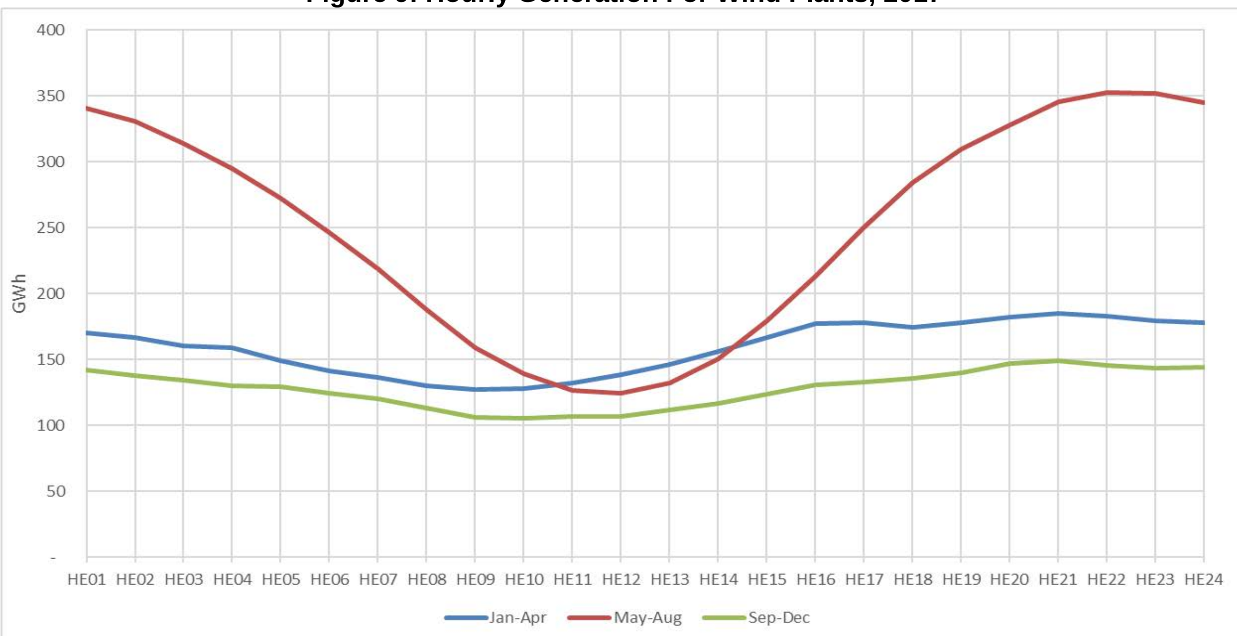


Source: California ISO aggregated data

Solar facilities maximize power output at noon each day when solar irradiance, the rate at which solar energy falls onto the Earth, is at its peak; this typically occurs a few hours before California's peak demand for electricity. The months of May through August provide the most solar energy due to the longer daylight hours available. For all periods, the solar generation peak occurs between 12:00 (HE12) and 1:00 p.m. (HE13) and then steadily drops to almost zero by 8:00 p.m. (HE20).

Figure 9 summarizes total annual wind energy for the same three groups of months across each hour of the day. Wind energy in California is generally most abundant in May through August, based on the larger temperature differentials created each day in the warm summer months. Wind energy tends to be most abundant after 1:00 p.m. (HE13), building to a peak around 10:00 p.m. (HE22), and then tapering off to minimum levels again by 12:00 p.m. (HE12). However, maximum wind energy availability falls a few hours after the time of the California ISO system peak and tends to be less available on above-average temperature days than during days of average or below-average temperatures.[21]

Figure 9: Hourly Generation For Wind Plants, 2017



Source: California ISO aggregated data

Solar and wind technologies are considered to be *intermittent resources* by the California ISO. As intermittent resources, they are able to schedule energy into the real-time market without incurring imbalance charges when the delivered energy deviates from the scheduled amount.[22] As energy deliveries from intermittent renewable resources enter the grid, dispatchable thermal or hydroelectric resources are cycled up or down to accommodate the natural fluctuations in output of the intermittent resources. It is this cycling of natural gas-fired plants that negatively impacts the individual heat rates but still provides overall fuel savings and reductions in GHG emissions for the state.

Similar to **Figure 7** for CC plants, aggregated, or combined, hourly data for 2017 for aging and peaking plants are shown in **Figure 10** and **Figure 11**. The two charts confirm that aging and

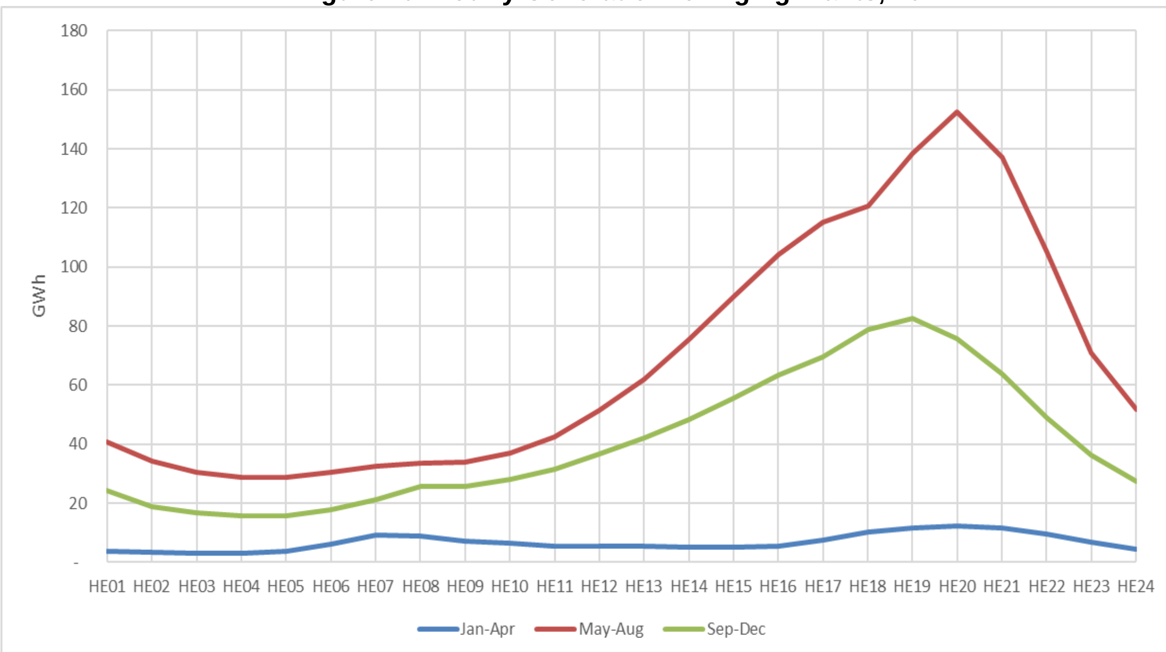
---

21 D. Metz, M. Nyberg, California Energy Commission, April 2008, *Staff Paper: Analysis of Electric Wind Generation on High Temperature and High Load Days in California,* CPUC R.08-01-025.

22 California ISO Participating Intermittent Resources, https://www.caiso.com/Pages/documentsbygroup.aspx?GroupID=38318ED0-1E40-494A-8539-7BB8A54ECEEF.

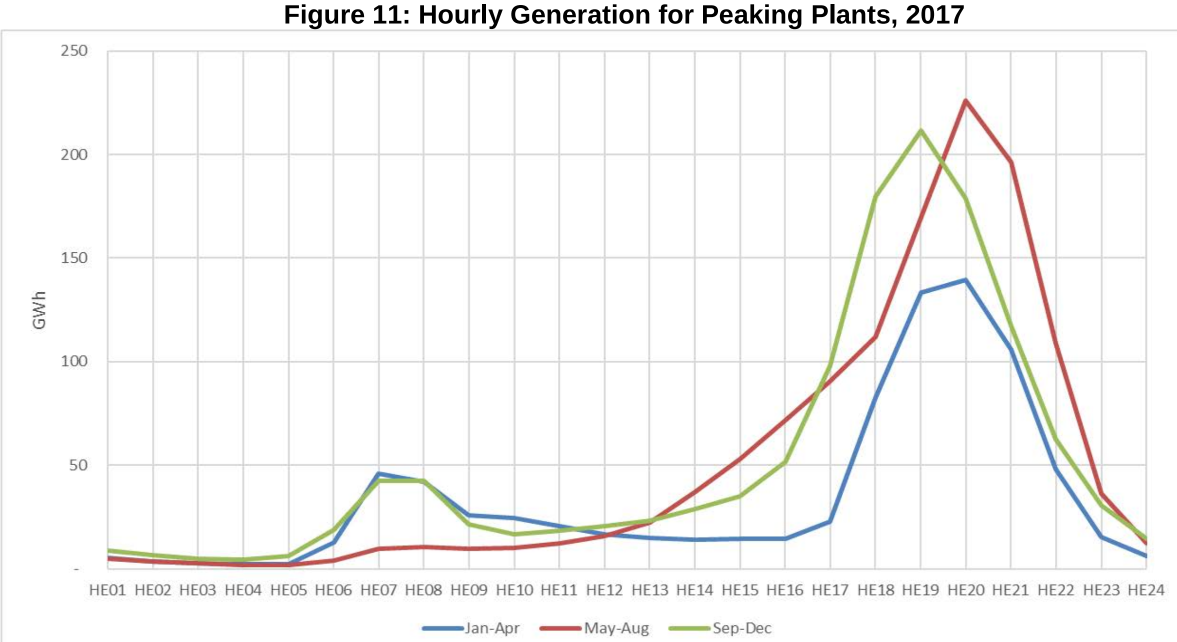
peaking plants deliver the most energy between 7:00 p.m. (HE19) and 8:00 p.m. (HE20) across all three groups of months.

Figure 10: Hourly Generation for Aging Plants, 2017



Source: California ISO aggregated data.

Figure 11: Hourly Generation for Peaking Plants, 2017



Source: California ISO aggregated data.

Hourly Generation at the Time of System Peak Load

The instantaneous peak load within the California ISO in 2017 was 50,016 MW and occurred at 3:58 PM on Friday, September 1. The peak came as a result of record-breaking temperatures as a high-pressure ridge stalled over California during the week of August 27 to September 2. By Friday, September 1, San Francisco reached 106° Fahrenheit (F), and Salinas in Monterey County recorded 109°F; both cities typically average 70°F on September 1.[23]

The instantaneous peak load for 2016 was 46,232 MW on Wednesday, July 27, at 4:51 p.m. The peak occurred as a heat dome – a ridge of high pressure trapping hot air over much of the country – spread into most of California. The heat dome caused much of California to experience a heat wave with very low humidity during the week of July 24 to July 30.

The operational attributes of CC, aging, and peaking as they operated on those days are shown in **Table 9**. Total output and operational statistics were similar for both CC and aging plants across both peak load days, though peaking plants were called into service for 64 percent more hours and doubled the total output on the peak-load day in 2017.

Table 9: California ISO Peak Load Day, 2016–2017

Hours Generating > 10 MWh	Combined Cycle		Aging		Peaking	
	7/27/2016	9/1/2017	7/27/2016	9/1/2017	7/27/2016	9/1/2017
Fleet: Total Generation (MWh)	274,434	275,215	78,083	76,889	20,492	40,862
Plant: Av. Hourly Output (MWh)	369	381	170	155	45	55
Plant: Std. Deviation (MWh)	178	169	142	156	25	42
Fleet: Operational Hours	743	723	458	496	455	746
Number of Generating Units	32	32	25	22	69	85

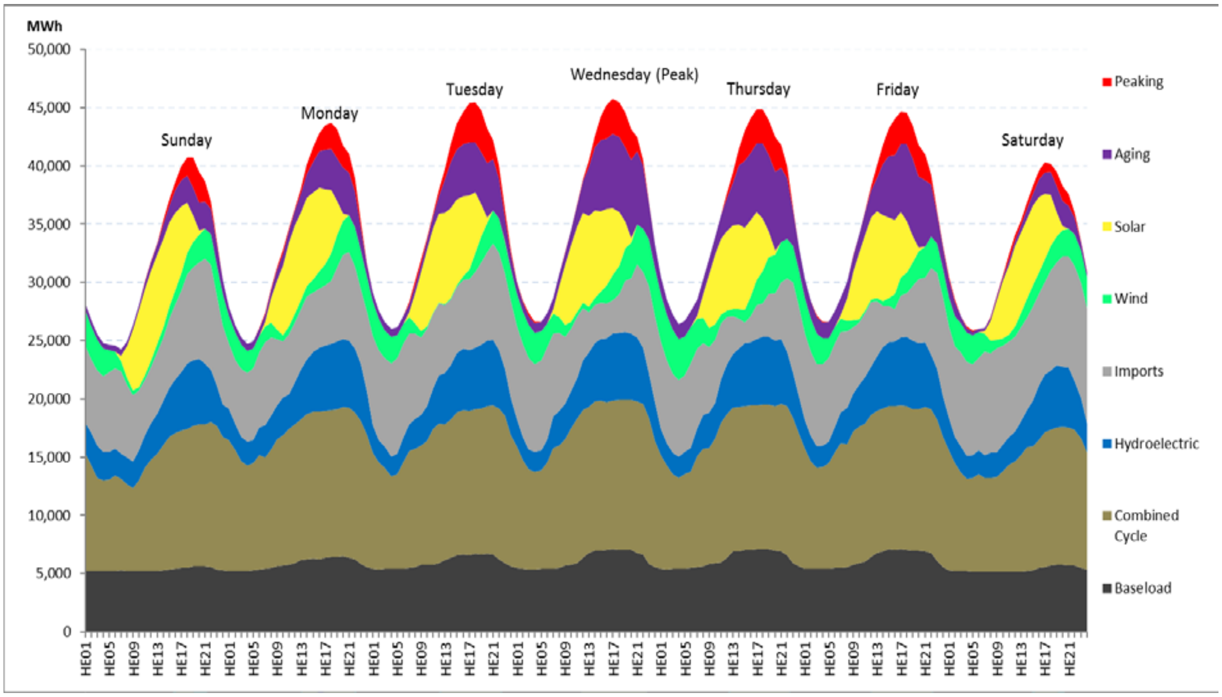
Source: California ISO aggregated data

Figure 12 and **Figure 13** show the contribution of aging, CC, and peaking generation to the total hourly loads across the week on which the peak-load day occurred within the California ISO for 2016 and 2017. Solar, wind, and hydroelectric generation are displayed separately along with a baseload generation category that groups energy from biomass, geothermal, nuclear, refinery waste-heat, petroleum coke, cogeneration, and miscellaneous technologies. Imports are classified separately as they are not distinguished by fuel type as they represent bulk energy transfers from neighboring balancing authorities. While there is some cycling of the baseload generation category during the peak-load hours of each day, both charts show significant ramping of the hydroelectric, aging, CC, and peaking categories that results from the natural variation and availability of both solar and wind energy. Peaking plants operated for longer hours into the evening hours on the September 1, 2017, as wind energy was less available

23 Weather.com, *All-Time Record-High Temperature Set in San Francisco; Record Heat Shifts to the Northwest This Week*, Linda Lam, September 4, 2017, https://weather.com/forecast/regional/news/west-heat-wave-all-time-record-heat-early-september-2017

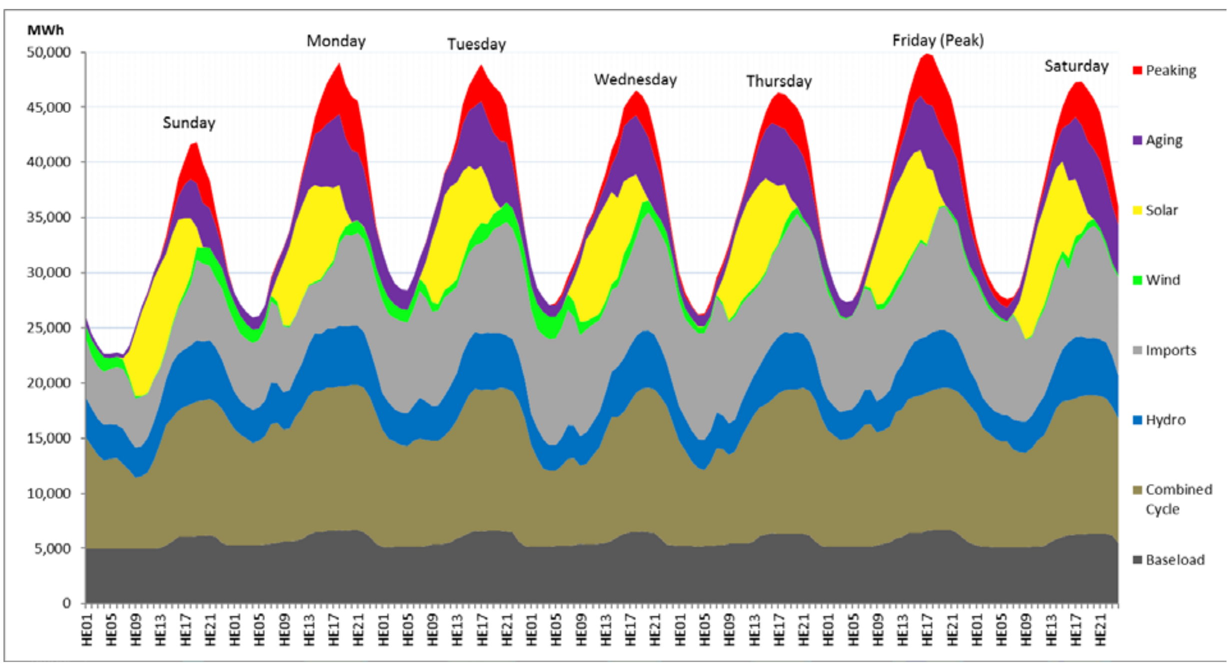
during those hours compared to the stronger wind generation profile on the peak-load week in 2016.

Figure 12: California ISO Hourly Generation Mix During July 24–30, 2016



Source: California ISO aggregated data

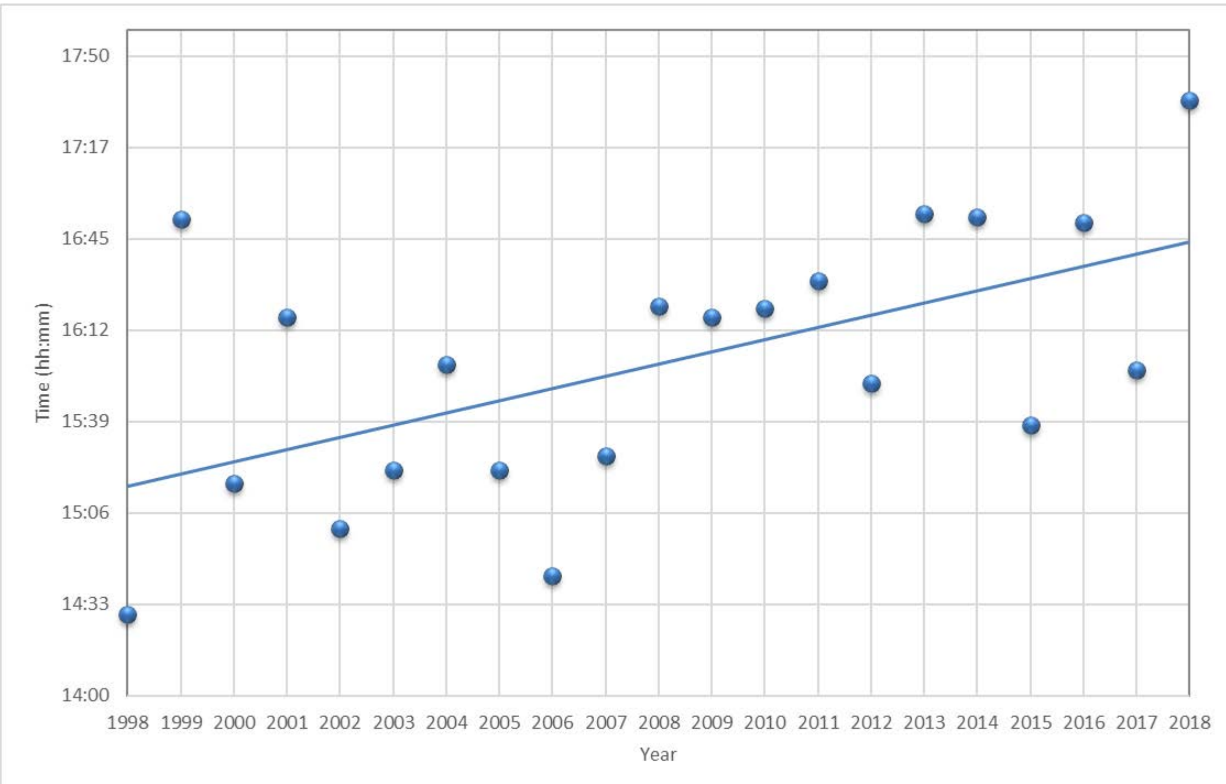
Figure 13: California ISO Hourly Generation Mix During August 27–September 2, 2017



Source: California ISO aggregated data

Figure 14 plots the times and associated trend line of the California ISO system peak load for January 1, 1998, through September 20, 2018.[24] The trend line suggests that the system peak is moving from early afternoon to the late afternoon hours. Part of the explanation for the shift may stem from the significant growth in distributed solar PV systems installed in residential, commercial, and industrial sites over the past 10 years. These distributed solar PV systems have significantly reduced load during the daylight hours with commensurate GHG emissions savings. As the sun wanes in the late afternoon hours and distributed solar PV generation falls in output, natural gas-fired generation is called upon to maintain the balance between supply and demand. This daily fluctuation results in the cycling observed of natural gas-fired generating units that results in a reduction in total natural gas-sourced GHG emissions based on the fuel savings with a slight loss of fuel efficiency as measured by the statewide heat rate.

Figure 14: Time of California ISO System Peak, 1998–2018



Source: California ISO website

24 California ISO website. Accessed August 22, 2017. https://www.caiso.com/Documents/CaliforniaISOPeakLoadHistory.pdf.

CHAPTER 6: Conclusion

California continues to benefit from a significant improvement in the systemwide thermal efficiency of its natural gas-fired power plant fleet over the past 17 years. From 2001 to 2017, the systemwide thermal efficiency has improved by 22 percent. This improvement in efficiency has remained above 20 percent in each year since 2007 and is attributed primarily to the increased reliance upon modern CC power plants and the phase-out of aging and OTC power plants.

The annual average heat rate for gas-fired generation increased slightly to 7,809 Btu/kWh in 2017 due to reduced operation of the gas fleet as hydroelectric generation increased by 50 percent and utility-scale solar PV generation increased by 25 percent. This large growth in zero-GHG energy displaced gas-fired generation and resulted in the capacity factor for the gas fleet dropping to below 25 percent, a level last observed in 2011. The capacity factor of the CC fleet also dropped from 40.7 percent to 35.9 percent in 2017. Finally, total natural gas fuel use for electric generation in California dropped by 9 percent in 2017 to the lowest level of the past 17 years, coming in at 839 million MMBtu, some 31 percent lower than 2001. The large growth in hydroelectric and utility-scale solar PV generation in 2017 resulted in more than 56 percent of California’s in-state generation coming from GHG-free resources.

Key Findings

- California’s natural gas-fired power plants burned the lowest total annual fuel in the past 17 years.
- Statewide average thermal efficiency has improved by 22 percent since 2001 due to the use of CC plants and the phase-out of OTC and aging plants.
- Hydroelectric generation increased 50 percent and solar PV generation increased 25 percent from 2016, displacing aging and CC generation.
- California’s non-GHG-emitting electric generation accounted for more than 56 percent of total in-state generation in 2017.
- CC plants were dispatched more aggressively in nonsummer months to meet a steeper load requirement compared to the summer months of May through August.
- The time of peak system load in the California ISO is occurring later in the day.

ACRONYMS

Acronym	Definition
BESS	Battery energy storage system
Btu	British thermal unit
California ISO	California Independent System Operator
CC	Combined cycle
CT	Combustion turbine
Energy Commission	California Energy Commission
GHG	Greenhouse gas
GWh	Gigawatt-hour
HRSG	Heat recovery steam generator
IEPR	*Integrated Energy Policy Report*
kWh	Kilowatt-hour
MMBtu	Million British thermal units
MW	Megawatt
MWh	Megawatt-hour
OTC	Once-through-cooling
QF	Qualifying facility
QFER	Quarterly Fuels and Energy Reports
PURPA	Public Utility Regulatory Policies Act of 1978
ST	Steam turbine

GLOSSARY

Term	Definition
Aging Plant	Natural gas-fired steam turbines that were built and operational before 1980.
Ancillary Services	Within the California ISO, the four types of ancillary services are regulation up, regulation down, spinning reserve, and non-spinning reserve. These services support the stable operation of the grid.
Baseload Generation	Power plants that are designed to operate at an annualized capacity factor of at least 60 percent.
Capacity Factor	A measure of the actual output of a power plant over a specific period compared to the total potential output a power plant could have provided by operating at its nameplate capacity over the same period.
Cogeneration Plant	A power plant that produces electricity and useful thermal energy (heat or steam) simultaneously.
Combined-Cycle Plant	A power plant has a generation block consisting of at least one combustion turbine, a heat recovery steam generator, and a steam turbine.
Dispatch	The action that signals a power plant to turn on or turn off.
Frequency Control	The ability to dispatch generation due to decreases in supply or increases in load within a power system.
Generating Unit	A combination of physically connected generators, reactors, boilers, combustion turbines and other prime movers operated together to produce electric power. In the context of this staff paper, a generating unit can only be assigned to a single natural gas-fired generation category.
Heat Rate	Expresses how much fuel is necessary (measured in British thermal units [Btu]) to produce one unit of electric energy (measured in kilowatt-hours [kWh]).
Higher Heating Value	In the determination of a heat rate, higher heating value includes the latent heat of vaporization of the water in the combustion of natural gas.
Load-Following	The ability to dispatch a power plant to meet changing system load requirements.
Lower Heating Value	In the determination of a heat rate, this measurement would not include the latent heat from the vaporization of the water.

Nonspinning Reserves	An ancillary service that requires non-operating plants to be capable of ramping up to full capacity and synchronizing to the grid within 10 minutes of dispatch.
Null Energy	Energy from a certified renewable energy power plant that has been separated from the associated renewable attributes and sold independently of the renewable energy credit.
Once-Through-Cooling	The usage of water from the ocean or other body of water to cool steam after it has passed through a turbine.
Peaking Plant	Fast-starting power plants intended to operate for short durations to meet peak-load system requirements.
Power Plant	A power plant is defined as a station composed of one or more electric generating units.
Ramping/Cycling	Similar to load-following, power plants altering output levels, including shutdowns and restarts, in response to changes in system load and the availability of renewable generation on the electrical grid. Includes the ancillary services of regulation up and regulation down.
Reactive Power	Reactive power supports the magnetic and electric fields required for alternating current power systems to function. It is a measure of the phase difference between current and voltage in an AC system.
Spinning Reserves	An ancillary service that recognizes operating power plants (that is, spinning) that are already synchronized and ready to meet electric demand within 10 minutes.
Unspecified Energy	Energy that cannot be attributed to a fuel source.
Voltage Control	In an alternating current power system, voltage control is defined as the ability to adjust for changes in reactive power.