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STAFF PAPER

Thermal Efficiency of Gas-Fired Generation in California: 2015 Update

Michael Nyberg

Supply Analysis Office

Energy Assessments Division

California Energy Commission

California Energy Commission

Edmund G. Brown Jr., Governor

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ABSTRACT

Senate Bill 1389 (Bowen and Sher, Chapter 568, Statutes of 2002) directed the California Energy Commission adopt an Integrated Energy Policy Report (IEPR) every two years. This staff paper supports the technical analyses required by the IEPR by describing general trends in the thermal efficiency of natural gas-fired generation in California from 2001 through 2014. Over this 14-year period, California's gas-fired generation has seen thermal efficiency improvements of 23 percent. The successful development of new combined-cycle plants continues to be the primary reason for the improvement in California's systemwide heat rate. The thermal efficiency of the state's current portfolio of noncogeneration natural gas power plants has resulted in 29 percent more energy being generated while using the same amount of natural gas compared to 14 years ago.

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

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CHAPTER 1: Thermal Efficiency

Following major electricity restructuring legislation in 1996, regulations to collect electric generation and fuel use data from power plant owners became effective on February 23, 2001. 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 technical analyses required by the IEPR by describing general trends in the thermal efficiency of natural gas-fired generation in California from 2001 through 2014. Over the 14-year period since 2001, California's gas-fired generation, excluding cogeneration, has seen thermal efficiency improvements of 23 percent.[1]

Table 1 depicts the almost steady reduction of the average heat rate over the 14 years.[2] The thermal efficiency of gas-fired generation 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 energy (measured kilowatt-hour [kWh]). Therefore, the heat rate of California's natural gas-fired generation is obtained by dividing the total fuel used by the total electrical energy generated. A lower heat rate indicates a more efficient system; however, there are practical limits to the state's achievable systemwide heat rate.

Table 1: California Average Annual Natural Gas-Fired Heat Rates (Btu/kWh)

	2001	2002	2003	2004	2005	2006	2007
Heat Rate	10,040	9,672	9,077	8,745	8,364	8,110	7,889
	2008	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
Heat Rate	7,947	7,859	7,634	7,881	7,806	7,666	7,760

Source: Quarterly Fuels and Energy Report (QFER) CEC-1304 Power Plant Data Reporting.

The data for this staff paper are obtained through the collection of the California Energy Commission's CEC-1304 Power Plant Owner Reporting Form. By regulation, all power plants with a nameplate capacity of 1 megawatt (MW) or more serving California end users must

1 2014 Average Heat Rate = 7,760 British thermal units per kilowatt hour (Btu/kWh).
2001 Average Heat Rate = 10,040 Btu/kWh.
Percentage Change in Heat Rate = (10,040 – 7,760) / 10,040 = 22.7 percent.

2 Annual figures in **Table 1**: California Average Annual Natural Gas-Fired Heat Rates (Btu/kWh) differ from previous staff papers due to the exclusion of cogeneration power plant data from the overall heat rate calculation due to the lack of available thermal efficiency data. Moreover, revised reports received under the Quarterly Fuel and Energy Reporting regulations (California Code of Regulations, Title 20, Division 2, Chapter 3, Section 1304[a][1]-[2]) were also incorporated into this report.

report the respective generation, fuel, and water use for each calendar year to the Commission. *Nameplate capacity* is defined as the maximum rated output of a generator under specific conditions as designated by the manufacturer. It is commonly indicated on a nameplate physically attached to the generator. The Commission compiles and posts the data publicly on the Commission's Energy Almanac website.[3] This is the fourth in a series of staff papers documenting the changes in thermal efficiency of gas-fired generation in California.

Trends in Heat Rates and Capacity Factors

The significant improvement in the thermal efficiency of California's gas-fired generation is due to an increase in generation from combined-cycle (CC) power plants built since 2000 and reduced dependency on generation from aging power plants. If the cogeneration category is included in this comparison, the efficiency gain over the past 14 years is reduced slightly to 18 percent due to the inclusion of fuel use for useful thermal output (steam) without a corresponding electric-energy equivalent as measured in kWh available for the cogeneration plants.[4] **Table 2** details the measured heat rates since 2001. Each category has a relatively consistent heat rate over the 14-year period, while the overall statewide average has fluctuated based on the mix of power in each year. Chapter 2 presents a detailed description of each category of natural gas power plants.

As mentioned above, without accounting for the unique aspect of the dual output of useful steam and electricity, California's cogeneration plants appear to operate at relatively high, inefficient heat rates. Over the past 14 years, this heat rate has been near or above 11,000 Btu/kWh. However, given that these plants are also producing steam, it is apparent that a heat rate that also accounted for this thermal output would be substantially less than the simple calculation of fuel input versus electricity output would indicate. The difficulty in assessing the gain in efficiency related to the output of steam and heat are beyond the scope of this paper. For this reason, the cogeneration data are not included in the average heat rate calculations in **Table 1**. This treatment is consistent with industry standards as exemplified in the United States Energy Information Administration's (U.S. EIA) Form EIA-860, *Annual Electric Generator Report*, and the corresponding summary of heat rates by *prime mover*.[5] Prime mover is defined as a device that converts one energy form, such as heat from fuels, into mechanical energy.

The capacity factors (CFs) shown in **Table 3** give an overview of how often California's fleet of natural gas power plants operated each year. A *CF* is the ratio of electric generation over a selected period divided by the maximum potential output over the same period. On

3 Energy Almanac. QFER CEC-1304 Power Plant Owner Reporting Database. Accessed August 2015. See http://energyalmanac.ca.gov/electricity/web_qfer/.

4 2014 Average Heat Rate with Cogeneration = 8,513 Btu/kWh.
2001 Average Heat Rate with Cogeneration = 10,325 Btu/kWh.
Percentage Change in Heat Rate = (10,325 – 8,513) / 10,325 = 17.5 percent.

5 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.

average, California's CC and cogeneration plants operated at 52 percent of the rated nameplate capacity, while aging and peaker gas plants operated at 5 percent CFs. This difference is to be expected based on an expectation of minimizing fuel costs by running California's more efficient CC plants and leaving the inefficient peaking and aging plants primarily for voltage support and local reliability. For example, the newly constructed 828 MW simple-cycle Marsh Landing Generating Station in Antioch (Contra Costa County), included in the peaker category, operated at less than a 1 percent CF over the past two years, while the similarly new 640 MW CC Russell City Energy Center in Hayward (Alameda County) operated at a 40 percent CF. These two examples illustrate the extreme operational differences between peaker and CC power plants.

Table 2: California Natural Gas-Fired Heat Rates for 2001 – 2014 (Btu/kWh)

	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Combined-Cycle	6,974	7,147	7,209	7,178	7,230	7,229	7,190	7,199	7,196	7,179	7,270	7,200	7,205	7,329
Aging	10,126	10,531	10,837	10,917	11,280	11,283	11,033	11,133	11,593	11,681	12,299	11,710	11,413	11,776
Cogeneration	10,932	10,957	10,976	11,174	11,274	11,231	11,146	11,299	11,142	10,962	11,015	11,050	11,173	11,244
Peaker	11,199	10,773	10,591	10,810	10,758	10,726	10,863	10,546	10,810	10,969	10,792	10,882	10,336	10,415
Other	10,142	9,528	10,354	9,883	9,862	9,952	9,940	10,052	10,509	9,915	9,477	9,432	9,350	9,131
State Average	10,325	10,232	9,861	9,644	9,452	9,092	8,815	8,837	8,741	8,573	8,896	8,546	8,456	8,513
State Average w/o Cogeneration	10,040	9,672	9,077	8,745	8,364	8,110	7,889	7,947	7,859	7,634	7,881	7,806	7,666	7,760

Source: QFER CEC-1304 Power Plant Data Reporting.

Table 3: California Natural Gas-Fired Power Plant Capacity Factors for 2001 – 2014

	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Combined-Cycle	67.8%	73.2%	71.1%	71.8%	66.0%	62.8%	64.3%	63.3%	61.5%	59.9%	59.4%	57.1%	56.0%	54.7%
Aging	41.8%	21.0%	15.4%	16.0%	9.9%	9.5%	9.0%	10.4%	7.6%	4.3%	4.1%	7.5%	5.8%	5.3%
Cogeneration	67.8%	73.2%	71.1%	71.8%	66.0%	62.8%	64.3%	63.3%	61.5%	59.9%	59.4%	57.1%	56.0%	54.7%
Peaker	8.9%	5.5%	4.1%	4.9%	4.4%	4.1%	4.3%	4.7%	4.1%	3.2%	3.6%	4.9%	4.7%	5.9%
Other	10.0%	9.7%	11.4%	12.7%	13.7%	11.8%	14.1%	14.4%	10.5%	12.0%	16.9%	19.3%	20.3%	20.0%
State Average	43.8%	32.4%	29.7%	33.2%	29.9%	30.8%	33.9%	34.6%	31.9%	28.9%	23.9%	31.9%	30.2%	30.8%

Source: QFER CEC-1304 Power Plant Data Reporting.

CHAPTER 2: Power Plant Categories and Capacities

The 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.

Combined-cycle power plants comprise the first category. A CC power plant has a generation block of consisting of a steam turbine and at least one combustion turbine (CT). The higher fuel efficiency results from the ability to use the waste heat from the CT to produce steam for the steam turbine. For this report, CC power plants consist of those generating units 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 2014, California had 34 large CC plants totaling almost 20,000 MW in nameplate capacity. These newer plants produce electricity with better heat rates than either stand-alone combustion turbines or steam turbines. Historically, these plants have been used for baseload power. However, with the increasing deployment of variable renewable generation and the inherent "must-take" characteristics for dispatch by grid operators, CC gas turbines are increasingly being tasked for flexible, load-balancing requirements that involve more frequent starts, ramping, and load-following ancillary services.

Ancillary services are reserved electric generating capacity that can be increased or decreased through automated 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).[6] Deficiencies between the hour-ahead and five-minute-ahead forecasts are met by adjusting the output of power plants via load following to ease changes, such as the integration of variable solar and wind renewable energy.

The Aging power plant category includes those plants built before 1980 and are composed almost exclusively of steam turbines that use once-through-cooling technology. Due to air quality and environmental concerns, aging power plants are being phased out or repowered with more efficient technologies. There were 27 power plants in 2001 with an operational nameplate capacity of almost 20,000 MW. By 2014, there were 18 operational aging power plants with a combined nameplate capacity of 13,315 MW. Power plant retirements included Contra Costa (680 MW), Humboldt Bay just south of Eureka (107 MW), Hunters Point in San

6 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.

Francisco (222 MW), Long Beach (585 MW), Magnolia in Burbank (108 MW), Morro Bay in San Luis Obispo County (912 MW), and Potrero in San Francisco (207 MW). Two aging steam units totaling 686 MW were retired at Los Angeles Department of Water and Power's Haynes Generating Station in Long Beach in June 2013.

The Cogeneration category consists of a mix of CTs, CC units, and steam turbines. They typically have relatively high heat rates and high CFs. Cogeneration plants, commonly referred to as combined heat and power plants, produce heat for an onsite or nearby dedicated thermal host, such as a cannery or college campus, and electricity for onsite industrial use or wholesale supply to the electrical grid.

Cogeneration plants tend to operate at higher average CFs compared to noncogeneration gas plants due to the continual steam requirements of the thermal host. Accordingly, heat rates for cogeneration plants that measure only the conversion of the chemical energy in natural gas to electrical energy, but do not incorporate a credit for the beneficial industrial use of useful steam, are not comparable to other noncogeneration gas plant heat rates. The number of cogeneration plants reporting is relatively consistent from 2001 through 2014: 148 and 136 plants, respectively. Total capacity for cogeneration plants in 2014 is 5,850 MW, down roughly 370 MW from what existed in 2001. The majority of cogeneration plants in California are less than 50 MW in size, often in the 1 MW to 10 MW range.

The Peaker plant category consists of those identified as having a peaking duty cycle role – specifically, those generating units that are called upon to meet peak demand loads for a few hours on short notice, often in the 15-minute- or 5-minute-ahead real-time market. This is the only category of generating units grouped together based on duty cycle. These plants typically use a fast-ramping, simple-cycle CT and are usually restricted in total hours of operation annually by air quality and environmental regulations. There were 29 peaker plants identified in 2001; by 2014 there were 74.

All remaining natural gas power plants fall into the Other category. These include new technologies such as fuel cell applications, reciprocating engine applications, turbine testing facilities, and older generating units built before the 2000s that are not considered to be peakers, cogeneration, or aging. This category also includes CC plants composed of repurposed older gas and steam turbines. There are fewer than 20 plants in this category for each year studied.

Table 4 summarizes in-state natural gas-fired electric generation in 2014, with breakouts for the five categories of natural gas-fired generation.

Table 4: California Natural Gas-Fired Power Plants Summary Statistics for 2014

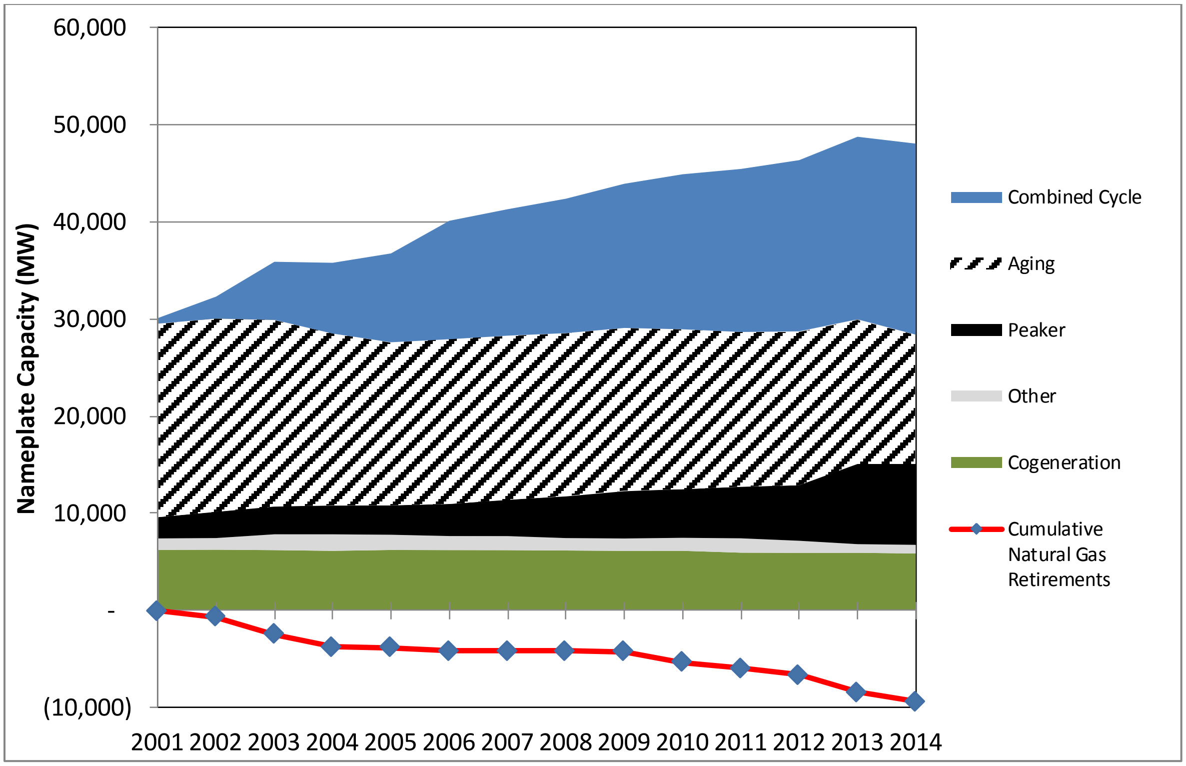
	Capacity (MW)	Share of Capacity	GWh	Share of GWh	Capacity Factor	Heat Rate (Btu/KWh)
All Categories of Natural Gas	48,067	100.0%	129,498	100.0%	30.8%	8,513
Cogeneration	5,850	12.2%	28,013	21.6%	54.7%	11,244
Noncogeneration Natural Gas Totals	42,217	87.8%	101,485	78.4%	27.4%	7,760
Combined-Cycle	19,675	40.9%	89,411	69.1%	51.9%	7,329
Aging	13,315	27.7%	6,226	4.8%	5.3%	11,776
Peaker	8,337	17.3%	4,288	3.3%	5.9%	10,415
Other	890	1.9%	1,560	1.2%	20.0%	9,131

Source: QFER CEC-1304 Power Plant Data Reporting.

The total annual operational capacity of each category is shown in **Figure 1.** Over the past 14 years, CC and peaker categories have experienced an overall increase in capacity, while cogeneration, other, and aging categories have declined. Cumulatively, by the close of 2014, nearly 9,400 MW of natural gas generation had been retired since 2001, as shown in **Figure 1**, by a single line below the stacked-area graph. **Figure 2** highlights the change in capacity from 2013 for each of the five categories.

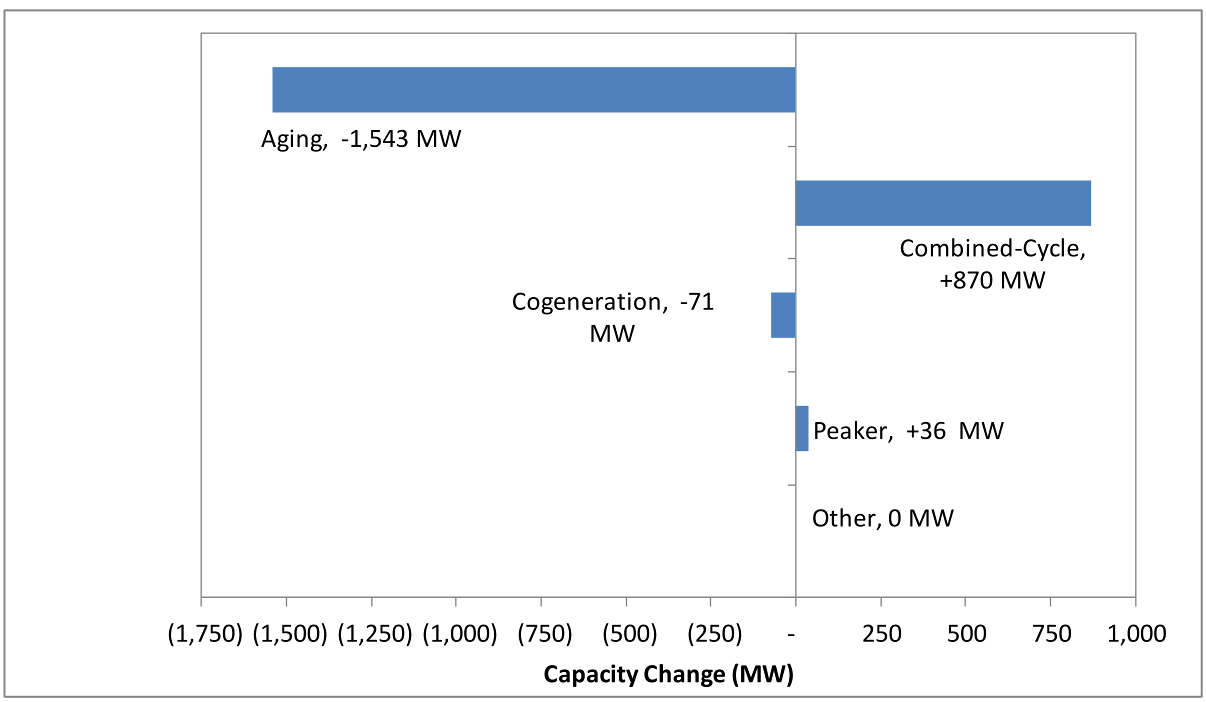
These data have been compiled based on the attributes of the generating units within each power plant. In this study, generating units are assigned to one of the five categories. For example, Moss Landing has four sets of units, two of which are classified as aging and two are new CC generator sets. All data categories are mutually exclusive, and no unit is double-counted.

Figure 1: Total Annual Operational Capacity by Plant Type



Source: QFER CEC-1304 Power Plant Data Reporting.

Figure 2: Change in Capacity 2014 Compared to 2013

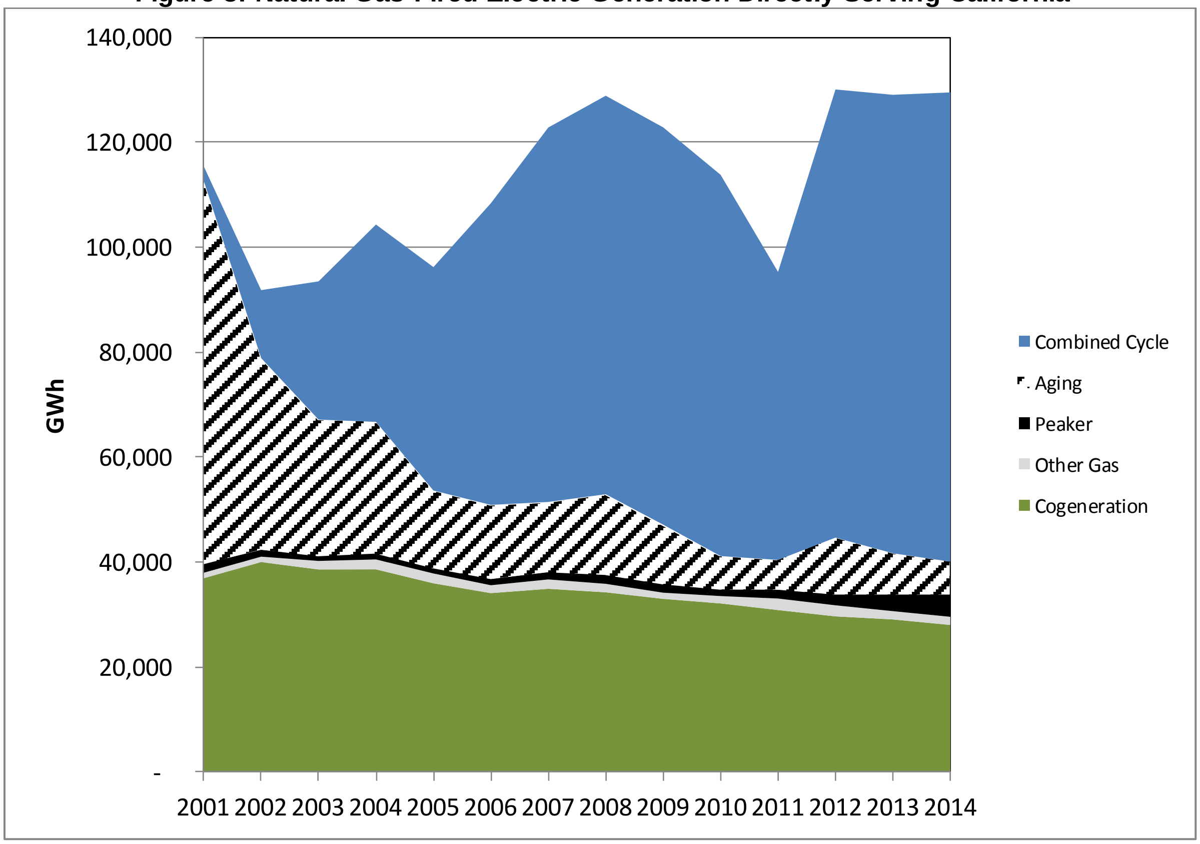


Source: QFER CEC-1304 Power Plant Data Reporting.

CHAPTER 3:
Natural Gas Generation

Natural gas is the dominant fuel source for electric generation in California in terms of both total power plant nameplate capacity and total energy supplied. In 2014, nearly 50,000 MW of natural gas generation capacity supplied 44 percent (129,498 gigawatt-hours [GWh]) of California's total electric energy needs for the year. **Figure 3** illustrates the annual electric energy from natural gas power plants directly serving California end users over the past 14 years.

Figure 3: Natural Gas-Fired Electric Generation Directly Serving California



Source: QFER CEC-1304 Power Plant Data Reporting.

CC plants comprised 40 percent of total natural gas capacity and provided 69 percent (89,411 GWh) of the total energy from gas-fired generation categories. Moreover, CC plants reduced California's reliance on aging plants to a level similar to that of 2010. As mentioned, the CC plants operated at an average capacity factor of 52 percent and had an average heat rate of 7,317 Btu/kWh in higher heating value terms.

In contrast, aging power plants accounted for only 5 percent (6,226 GWh) of gas-fired electric generation but still held 28 percent of the state's total gas-fired capacity (see

Figure 3), nominally down only 6,616 MW from the 2001 level of 19,931 MW. These aging plants operated at a 5 percent CF in 2014, compared to a 42 percent CF in 2001, with an average heat rate of 11,776 Btu/kWh. The low CF indicates the primary value of these plants is in providing capacity support for local reliability that may include *voltage control, frequency control*, and other ancillary services.[7] Control of voltage and frequency within a power system are essential to maintaining the balance between generation and load. Voltage control is defined as the ability of a power system to adjust for changes in *reactive power*. Reactive power supports the magnetic and electric fields required for alternating current power systems to function. Frequency control is defined as the ability to dispatch generation due to decreases in supply or increases in load within a power system.

Figure 4 shows how the collective average heat rate for gas-fired generation in California has improved over the past 14 years. This trend has been consistent and the efficiency gains have been cumulative. These gains in power plant efficiency result in direct reductions in greenhouse gas (GHG) emissions as the heat rate is directly proportional to GHG emissions. The impact of the ongoing drought, coupled with the closure of the San Onofre Nuclear Generation Station in 2012, has resulted in generally higher CFs for California's natural gas power plants; however, while the increased CFs help increase fuel-burn efficiency, this efficiency comes at a cost of increased overall GHG.

As judged by the slope of the statewide average heat rate trend line in **Figure 4**, the greatest efficiency gains occurred from 2001 through 2007, when the majority of CC plants began commercial service. The displacement of gas-fired generation by abundant hydroelectric power in 2011 caused the slight increase in the heat rate. Accordingly, natural gas units operated fewer hours at more inefficient fuel consumption levels over that year. By 2012, the downward trend in the statewide heat rate resumed with CC heat rates flattening out at 7,200 Btu/kWh, resulting in a system average heat rate of 7,666 Btu/kWh in 2013. Both the CC and the system average heat rates crept up in 2014 (7,329 Btu/kWh and 7,760 Btu/kWh, respectively) primarily due to increased renewable generation integration with the grid, which requires some natural gas plants to operate in a load-following capacity. This operation resulted in a slight efficiency loss for CC plants compared to previous years.

Figure 5 illustrates how power generated from CC plants has surpassed (or displaced) the peak generation from aging power plants in recent years. In 2001, aging power plants generated 63 percent (73,041 GWh) of total energy from natural gas, while CC plants generated only 2 percent (2,730 GWh). By 2014, CC gas plants generated 69 percent (89,411 GWh) of total energy from natural gas while aging plants accounted for less than 5 percent (6,226 GWh), a complete reversal in roles from 2001. The total capacity of CC plants in 2014 of 19,675 MW almost equaled the total capacity of California's aging plants in 2001 at 19,931 MW. Aging plants account for 13,315 MW of nameplate capacity in 2014.

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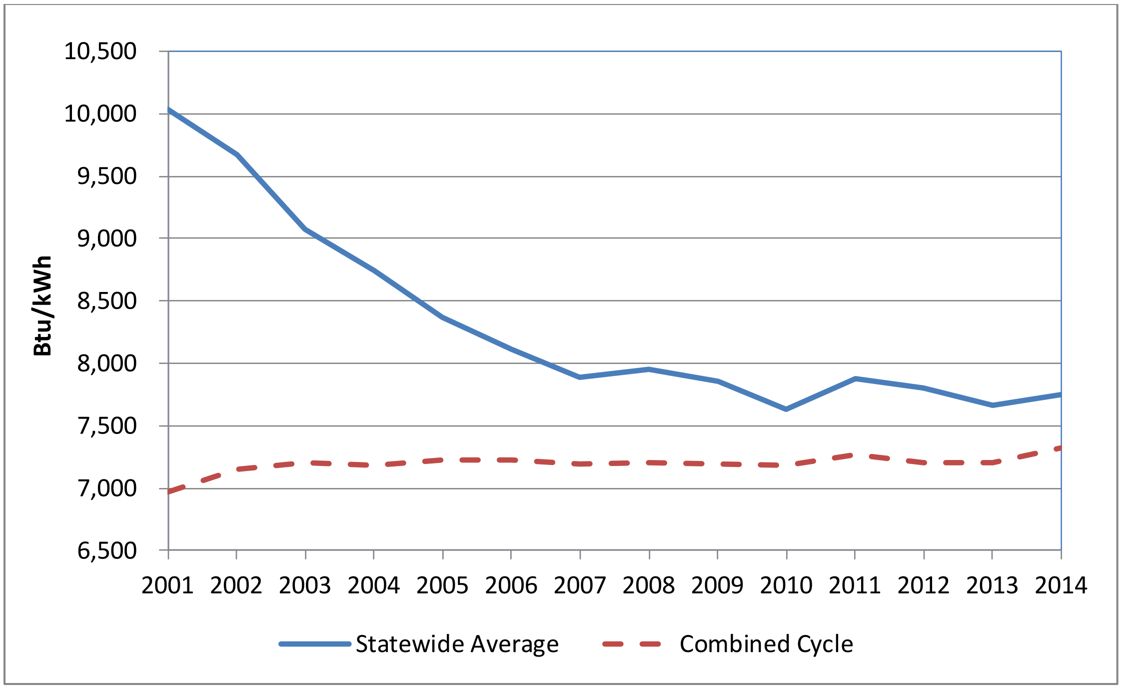
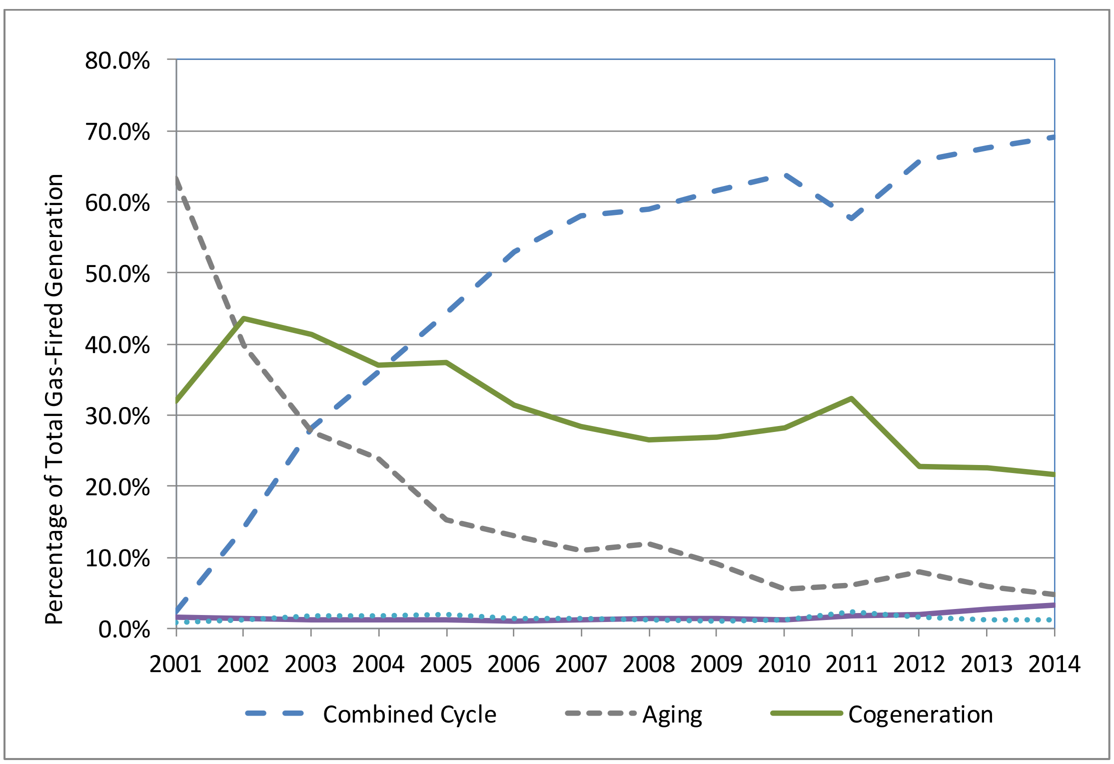
7 California Energy Commission. *The Role of Aging and Once-Through-Cooling Power Plants in California — An Update.* CEC-200-2009-018. See http://www.energy.ca.gov/2009publications/CEC-200-2009-018/CEC-200-2009-018.PDF.

Figure 4: Average Heat Rates for Gas-Fired Electric Generation Serving California



Source: QFER CEC-1304 Power Plant Data Reporting.

Figure 5: Percentage of Total Gas-Fired Generation by Plant Type



Source: QFER CEC-1304 Power Plant Data Reporting.

Table 5 and **Table 6** show the energy and fuel use for each category over the past 14 years. In 2014, California's natural gas plants generated 14,061 GWh more than 2001 and used 89,443 GBtu (10^9 British thermal units) less than was used in 2001. If the Cogeneration category is removed from the comparison due to the complication of accounting for useful thermal output, the efficiency improvement is 29 percent over the 14-year period. This efficiency improvement in the state's mix of natural gas 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: Electric Generation From California's Natural Gas-Fired Power Plants (GWh)

	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Combined-Cycle	2,730	12,954	26,335	37,605	42,576	57,481	71,357	75,936	75,706	72,649	54,878	85,397	87,361	89,411
Aging	73,041	36,535	25,886	24,940	14,644	14,138	13,347	15,307	11,200	6,220	5,691	10,433	7,589	6,226
Cogeneration	36,927	40,001	38,587	39,606	35,950	34,082	34,905	34,236	32,988	32,117	30,858	29,652	29,067	28,013
Peaker	1,699	1,303	1,045	1,271	1,161	1,172	1,412	1,770	1,764	1,401	1,675	2,468	3,439	4,288
Other	1,040	1,029	1,631	1,897	1,878	1,501	1,791	1,618	1,179	1,407	2,193	2,110	1,582	1,560
State Total	115,437	91,822	93,486	104,319	96,210	108,374	122,812	128,867	122,836	113,794	95,294	130,060	129,037	129,498

Source: QFER CEC-1304 Power Plant Data Reporting.

Table 6: Natural Gas Fuel Use for California's Power Plants (Thousand MMBtu)

	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Combined-Cycle	19,036	92,581	189,850	269,908	307,828	415,525	513,084	546,692	544,811	521,541	398,968	614,866	629,449	655,259
Aging	739,591	384,769	280,521	272,272	165,192	159,512	147,256	170,401	129,845	72,659	69,993	122,167	86,616	73,313
Cogeneration	403,696	438,293	423,517	431,382	405,302	382,787	389,073	386,820	367,544	352,074	339,888	327,657	324,769	314,976
Peaker	19,030	14,042	11,072	13,744	12,493	12,569	15,336	18,670	19,071	15,367	18,075	26,861	35,543	44,662
Other	10,543	9,805	16,891	18,742	18,521	14,937	17,800	16,266	12,386	13,947	20,785	19,898	14,787	14,243
State Total	1,191,896	939,489	921,851	1,006,048	909,335	985,329	1,082,547	1,138,848	1,073,657	975,588	847,709	1,111,449	1,091,164	1,102,453

Source: QFER CEC-1304 Power Plant Data Reporting.

Hydroelectric Generation and Drought Impacts

California has had to rely upon strong levels of CC electric generation to offset years when available hydroelectric generation is well below average. Snowmelt and runoff in California peak in the spring months, but water is conserved in reservoirs to maximize hydroelectric energy production during the summer months. In wet years, natural gas-fired generation is *displaced* (reduced) by low-cost hydroelectric generation. This reduction in natural gas-fired generation (compared to average years) occurs almost entirely among CC power plants. The displacement is observable in **Figure 3** during 2011 (a wet year) with the large drop in CC electric generation. With the exception of the cogeneration fleet, this category is the only one large enough to match the available hydroelectric generation. Cogeneration plants are unable to be displaced by hydroelectric availability due to the steady steam requirements of the thermal hosts.

In a dry year, the fleet of CC power plants must increase energy production. In a severe, multiyear drought, energy production at CC power plants will be above average in all months, especially spring and fall.

While there is no statewide definition of what constitutes a wet (or dry) year, the California Department of Water Resources (DWR) has official water year classifications for the Sacramento Valley and for the San Joaquin Valley.[8] The water year begins on October 1 and runs to September 30. Thanks to the natural storage of water in the Sierra Nevada snowpack and in man-made reservoirs, variations in water year runoff correlate well with calendar year energy production in the Sacramento Valley and the San Joaquin Valley hydrologic regions. The San Joaquin Valley classification can be used for the Tulare Lake hydrologic region that includes the southern Sierra. Total hydroelectric generating capacity in California is about 13,800 MW of which 10,620 MW (or 77 percent) is located in the Sacramento Valley, San Joaquin Valley, or Tulare Lake hydrologic regions. For the 3,180 MW of hydro capacity located outside these three regions, more than 2,950 MW (about 93 percent) is located along major aqueducts and their reservoirs.

In simple terms, a wet year occurs about one year in five, and a dry year also occurs about one year in five. However, wet years and dry years do not occur randomly; they tend to cluster to produce wet periods (1982-1984, 1995-2000, and 2005-2006) and droughts (1976-1977, 1987-1992, 2001-2002, 2007-2008, and 2012-2015). Within each water year, California's Mediterranean climate normally has wet months and extremely dry months as summarized by DWR:

> On average, 75 percent of California's annual precipitation occurs from November through March, with 50 percent occurring from December through February. California's average precipitation is dependent on a relatively small number of

8 California Department of Water Resources, California Cooperative Snow Surveys, published online January 19, 2016, retrieved on January 20, 2016, from http://cdec.water.ca.gov/cgi-progs/iodir_ss/wsihist.

storms; a few storms more or less during the winter season can determine if the year will be wet or dry.[9]

The last wet year was 2011, which was characterized by a heavy and late-melting Sierra snowpack that helped provide some 42,731 GWh of hydroelectric energy. During the current drought that began in 2012, statewide hydro generation has fallen for four consecutive years. Accordingly, hydroelectric generation in California has decreased dramatically: down 36 percent in 2012, an additional 12 percent in 2013, and another 32 percent in 2014. In 2011, hydroelectric generation accounted for 23 percent (42,731 GWh) of total in-state generation; by 2014 it had fallen to 8 percent (16,478 GWh).

On January 17, 2014, Governor Brown officially declared the state to be in a drought. Calendar year 2014 would prove to be California's warmest year on record over the past 120 years. The average winter temperature in California was 48.0°F, 4.4°F above the 20th century average.[10] By the end of 2014, California's annual precipitation was 19.90 inches and ranked as the 44th driest over the past 120 years. As a result, in-state hydroelectric generation fell to 16,478 GWh.[11] **Figure 6** highlights the close but inverse relationship of hydroelectric and natural gas generation in California.

Also apparent in **Figure 6** is the large growth in renewable generation since 2010 offsetting the low hydroelectric generation in recent years. In 2014, wind and solar generation made up 12 percent, or 23,554 GWh, while hydroelectric generation provided only 8 percent of California's generation. Taken together, the three categories of solar, wind, and hydroelectric generation account for 20 percent, or 40,032 GWh, of total in-state generation, a level similar to wet-year hydroelectric generation in the state.

California's Total System Power

Total system power is a method of accounting for the complete profile of generation serving California by showing the total annual energy requirement for all load-serving entities with end-use loads in California. **Figure 7** summarizes the energy contribution from each of the five natural gas-fired power plant categories, along with all other fuel types serving California, to provide the context of gas-fired generation within the total system power mix.

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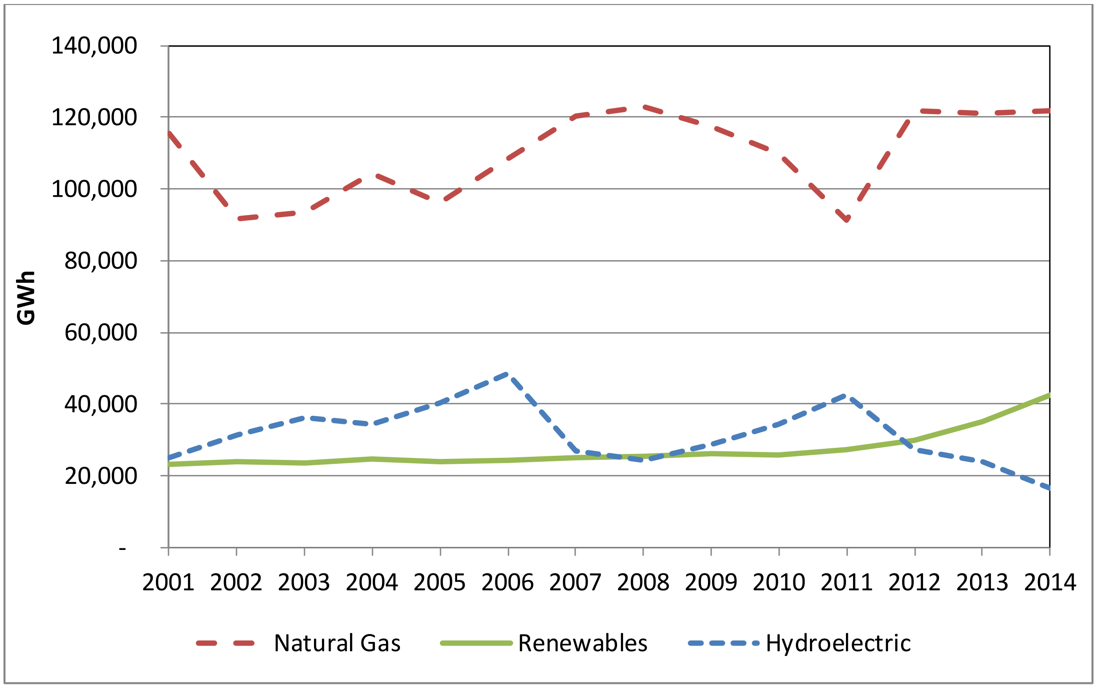
9 California Department of Water Resources, Drought Background, retrieved on January 20, 2016, from http://www.water.ca.gov/waterconditions/background.cfm.

10 NOAA National Centers for Environmental Information, State of the Climate: National Overview for Annual 2014, published online January 2015, retrieved on October 23, 2015, from http://www.ncdc.noaa.gov/sotc/national/201413.

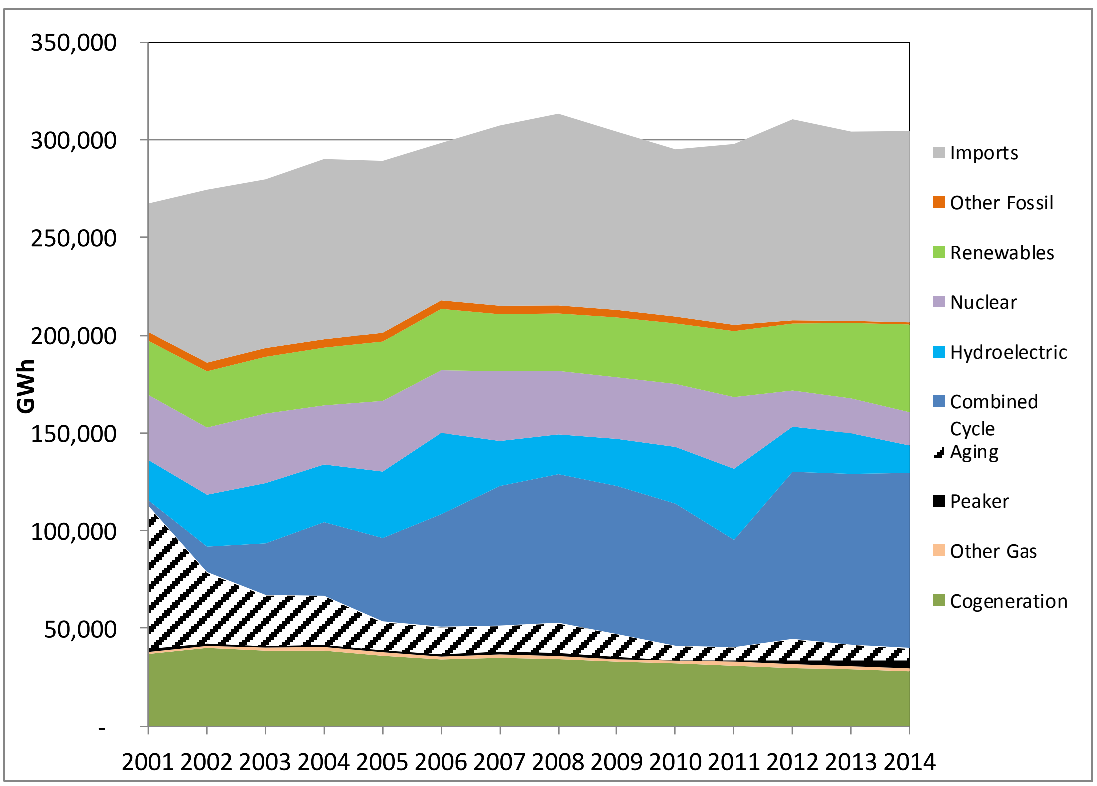
11. National Oceanic and Atmospheric Administration (NOAA) National Centers for Environmental Information, State of the Climate: Drought for Annual 2014, published online January 2015, retrieved on October 23, 2015, from http://www.ncdc.noaa.gov/sotc/drought/201413.

Figure 6: California Renewable, Hydroelectric, and Natural Gas Electric Generation



Source: QFER CEC-1304 Power Plant Data Reporting.

Figure 7: California Total System Power



Source: QFER CEC-1304 Power Plant Data Reporting.

California generates roughly two-thirds of its power (about 200,000 GWh) from power plants within the state and imports the remaining one-third of its power (nearly 100,000 GWh) from surrounding states within the Western Electricity Coordinating Council (WECC) region. The WECC is a non-profit corporation that exists to assure a reliable electric system in the western United States, western Canada, and northern Baja Mexico.

Imported energy plays a large role in shaping the state's overall efficiency. Part of this imported energy is composed of long-term contracts by California utilities with out-of-state renewable and nonrenewable power plants, referred to as *specific claims* by utilities. The remainder of the imported energy category is from short-term, spot market purchases that can also be considered specific claims if a power plant is identified or, if the original power source is not able to be identified, *unspecified power*. Unspecified power is power that cannot be directly sourced back to the originating power plant and makes up about 15 percent of total system power.

Generally, the unspecified power category would consist of short-term market purchases from those power plants that do not have a contract with a California utility. Much of the Northwest spot market purchases would probably be served by surplus hydroelectric and CC power plants. Spot market purchases from the Southwest would most likely be composed of energy from CC and coal power plants as the large solar renewable projects would be purchased under long term, specified, contracts. Finally, there is the issue of null power. *Null power* refers to power that was originally renewable power but from which the renewable energy credits have been unbundled from the energy and sold separately. Renewable energy credits do not have to be used in the same year as the associated energy procured. Accordingly, null power is not attributable to any technology or fuel type and may make up some portion of unspecified power in any given year.

CHAPTER 4:
Changes in Generation, 2013 vs. 2014

Table 7 illustrates operational differences between 2013 and 2014 for three categories of natural gas power plants that operate within the California ISO balancing area. The California ISO is one of four balancing authorities in California and manages almost 80 percent of the state's total electric service territory. The information used in **Table 7** is based on hourly data obtained from the California ISO. For each year, an annual average output was calculated using all available operational hours along with averages for a high load day and a low load day in each year.

Table 7: Average Hourly Gas-Fired Generation Summary

	Combined-Cycle		Aging		Peakers	
	2014	**2013**	**2014**	**2013**	**2014**	**2013**
Annual Generation (MWh)	70,480,000	71,232,000	4,103,000	5,126,000	3,471,000	2,501,000
Average Hourly Output (MWh)	348	373	91	100	47	47
Standard Deviation (MWh)	183	177	95	115	57	48
High Load Day	**9/15/2014**	**8/30/2013**	**9/15/2014**	**8/30/2013**	**9/15/2014**	**8/30/2013**
Generation Output (MWh)	270,975	267,356	73,554	68,624	22,357	34,603
Average Hourly Output (MWh)	391	415	142	228	46	56
Standard Deviation (MWh)	169	174	127	185	52	56
Low Load Day	**2/16/2014**	**2/17/2013**	**2/16/2014**	**2/17/2013**	**2/16/2014**	**2/17/2013**
Generation Output (MWh)	195,908	155,546	1,488	1,386	3,478	1,345
Average Hourly Output (MWh)	313	323	65	29	58	45
Standard Deviation (MWh)	184	169	53	19	69	23

Source: California ISO aggregated data.

The high load day listed in **Table 7** for 2014 is September 15, 2014. It was the California ISO's highest load day of the year. The second highest load day in 2013, August 30, 2013, was selected due to its proximity to the 2014 high load day so as to keep the number of available daylight hours for solar generation similar between the two years. Both dates are weekdays as weekend dates have significantly different load profiles.

The net change in generation on comparable peak load days provides some insight into how the different generation technologies affect each other. In 2014, solar and wind generation appear to have made up for the loss of available hydroelectric generation resulting from the ongoing drought. Furthermore, natural gas generation from aging, CC, and peakers is also less both in total energy and as a percentage of all fuel types than on a similar high load day in 2013.

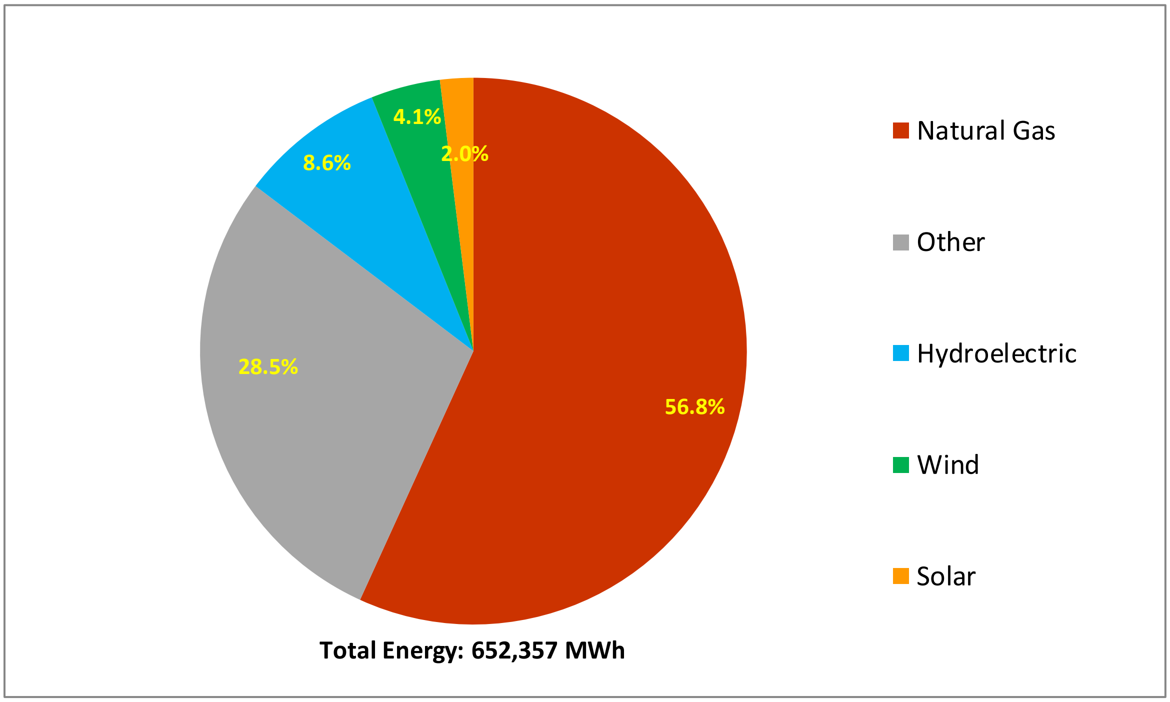
In comparing the operation of CC units across both years, the average hourly output of 348 megawatt-hours (MWh) in 2014 was 7 percent lower than the previous year, while the annual generation was within 1 percent, virtually the same in each year. This implies CC units operated over more hours throughout the year at reduced levels of output in 2014 compared to 2013. Moreover, the variability of hourly output, as defined by the standard deviation, was 4 percent higher at 183 MWh compared to 177 MWh in 2013. The lower average hourly output combined with the slightly higher variability in 2014 suggests that CC units may have been dispatched more frequently to integrate must-take renewable generation.

Aging units had an average hourly output of 91 MWh in 2014, about 8 percent lower than 2013, as well as 18 percent lower in variability at 95 MWh. The result is that aging plants operated fewer hours in 2014 than 2013. This is to be expected as aging power plants are more expensive to operate than newer power plants and tend to be used primarily for local reliability, through the provision of capacity support in the event of a major equipment failure at a nearby power plant or transmission outage.

Peaker units had similar levels of average hourly output, 47 MWh, over both years, However, they operated over more hours and contributed 40 percent more energy in 2014 (3,471 GWh) than 2013 (2,501 GWh). Accordingly, they had 18 percent more variability in output, indicating they may also be supporting the integration of variable renewable energy due to the inherent fast-ramping capabilities.

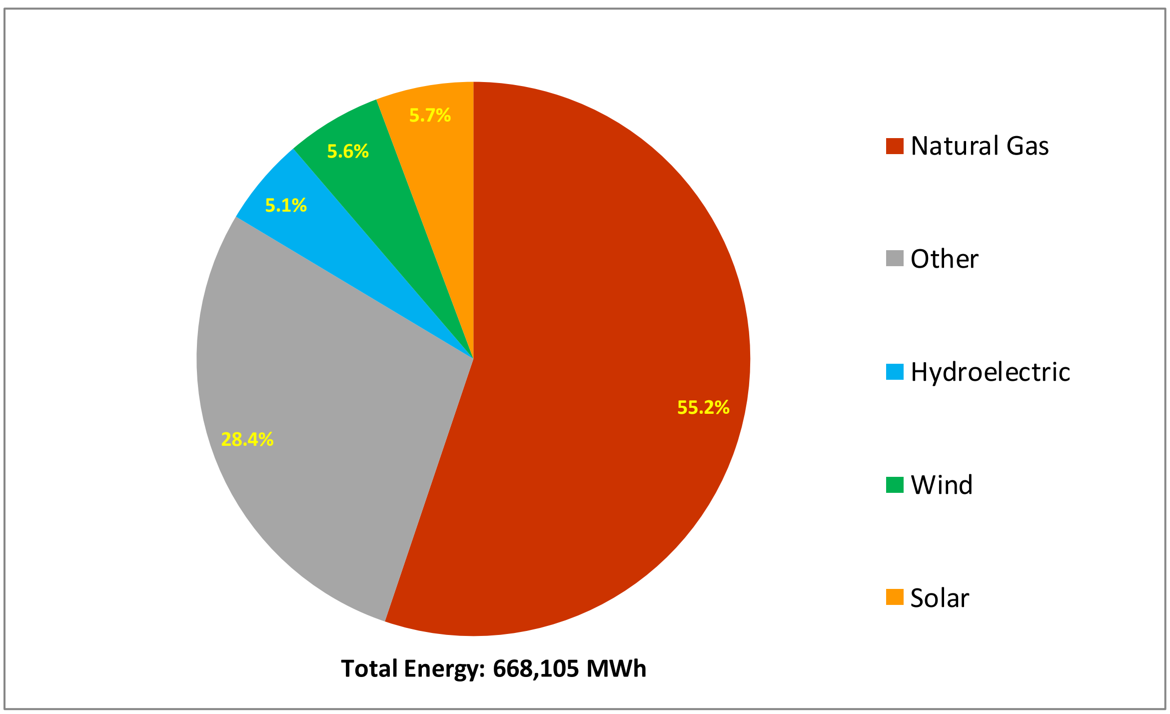
Figure 8 and **Figure 9** show the contribution of CC, aging, and peaker plant generation, combined into a natural gas category, to the total load across all 24 hours for the selected high load days. The impact of the large growth in wind and solar generation serving the California ISO appears to have resulted in a drop in the combined energy served by CC, aging, and peaker plants. The remaining generation categories of biomass, geothermal, nuclear, waste heat turbines, petroleum coke, and cogeneration (natural gas) were grouped together under the other category and varied little in the comparison. The 3.5 percent drop in hydroelectric generation also appears to have been made up from newly added wind and solar generation resources.

Figure 8: California ISO Fuel Types on High Load Day in 2013



Source: California ISO aggregated data.

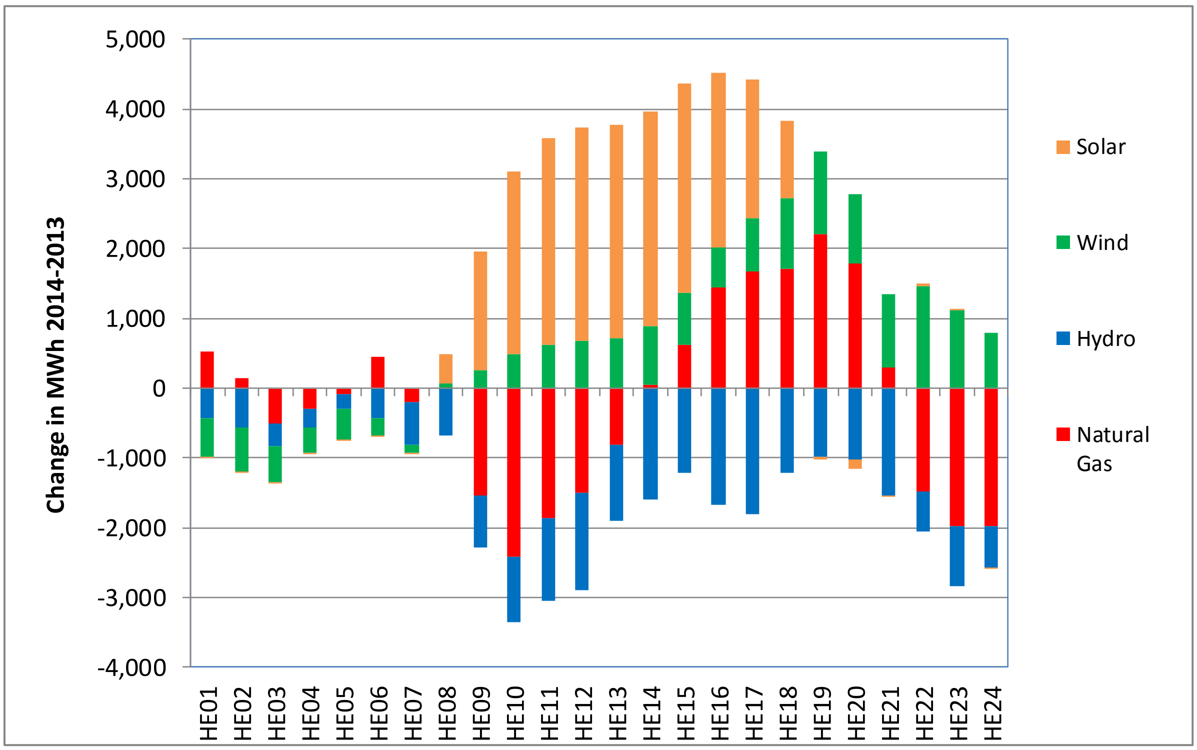
Figure 9: California ISO Fuel Types on High Load Day in 2014



Source: California ISO aggregated data.

The chart in **Figure 10** compares each hour of a high load day in 2014 to a comparable high load day in 2013 by displaying the net change in the amount of generation by technology type serving load. Using the same category groupings as used in **Figure 8** and **Figure 9,** the chart attempts to show changes in the type of electric generation technologies used in 2014 compared to 2013. For example, the orange bars for hour-ending 8:00 a.m. (HE08) through 6:00 p.m. (HE18) indicate solar generation was higher in 2014 than it was in 2013 across those hours. Conversely, natural gas generation showed reduced levels of output for HE09 through HE13 and increased levels of output during HE14 through HE21 in 2014.

Figure 10: Peak Day Hourly Difference in Generation 2014 – 2013



Source: California ISO aggregated data.

The growth in solar and wind generation in 2014 appears to affect the dispatch of natural gas plants during three specific periods of the day: from HE09 through HE13, from HE15 through HE20, and from HE22 through HE24. Each of these three periods illustrates how natural gas plants are being dispatched for load following in 2014 to accommodate the ramping up and down of available renewable generation. In the midmorning through noon hours, from HE09 through HE13, solar energy works toward its maximum output and natural gas plants are ramped down. As solar energy begins to fade from 3:00 p.m. (HE15) through 8:00 p.m. (HE20), natural gas plants ramp up to make up for the falling solar generation and to meet the peak demand load of the electric grid, which typically falls between 4:00 p.m. and 6:00 p.m. Finally, as wind speeds intensify in the later evening and overnight hours, from 10:00 p.m. (HE22) through 12:00 p.m. (HE24), natural gas plants are ramped back down to accommodate the significant wind generation supplies. From midnight through 8:00 a.m. (HE08), wind energy typically falls off, and natural gas plants resume normal operation until solar energy resumes once again the following day.

Overall, the growth in wind and solar generation in 2014 resulted in observable changes in natural gas generation over specific hours of the day. The across-the-board negative values for hydroelectric generation highlight the continued effects of the drought and the resulting lack of available hydroelectric generation in 2014.

CHAPTER 5: Conclusion

California has experienced a significant improvement in the thermal efficiency of its in-state natural gas power plants over the last 14 years. From 2001 to 2014, thermal efficiency has improved 23 percent. This improvement in efficiency is due to the increased reliance upon new CC power plants that are operating at a 52 percent CF. By contrast, aging power plants are operating at a 5 percent CF, down from 42 percent in 2001.

California has benefitted from this improved thermal efficiency in terms of GHG emission reductions, although the closure of the San Onofre Nuclear Generating Station in 2012 and the ongoing drought have temporarily dampened this effect. While natural gas generation continues to provide the necessary available capacity to offset unplanned capacity losses from other forms of generation, the substantial increases in renewable generation from wind and solar are helping provide long-term GHG emission reductions. Overall, any temporary increases in emissions from the power generation fleet should not impact the state's ability to achieve a reduction in GHG emissions to 1990 levels by 2020, as mandated by Assembly Bill 32, the Global Warming Solutions Act (Núñez, Chapter 488, Statutes of 2006).

ACRONYMS

Acronym	Definition
Btu	British thermal unit
California ISO	California Independent System Operator
CC	Combined cycle
CF	Capacity factor
CT	Combustion turbine
GHG	Greenhouse gas
GWh	Gigawatt-hour
IEPR	Integrated Energy Policy Report
kWh	Kilowatt-hour
MMBtu	Million British thermal units
MW	Megawatt
NOAA	National Oceanic and Atmospheric Administration
QFER	Quarterly Fuels and Energy Report
U.S. EIA	United States Energy Information Administration
WECC	Western Electricity Coordinating Council