STAFF PAPER

Thermal Efficiency of Gas-Fired Generation in California: 2014 Update

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ABSTRACT

This staff paper describes general trends in natural gas-fired generation in California from 2001 through 2013. Over this 13-year period, California's gas-fired generation has seen thermal efficiency improvements of more than 17 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 natural gas power plants has resulted in 12 percent more energy being generated while using 7 percent less natural gas compared to 13 years ago.

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

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Table of Contents

LIST OF FIGURES

LIST OF TABLES

Discussion

This staff paper describes some general trends in the thermal efficiency of natural gas-fired generation in California from 2001 through 2013. Over this 13-year period, California's gas-fired generation has seen thermal efficiency improvements of more than 17 percent.[1] **Table 1** depicts the steady improvement of the average heat rate over the 13 years. The thermal efficiency of gas-fired generation is typically described by measuring its heat rate. The heat rate of a power plant expresses how much fuel is necessary (measured in British thermal unit [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 energy produced. 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 for 2001 – 2013 (Btu/kWh)[2]

	2001	2002	2003	2004	2005	2006	2007
Heat Rate	10,331	10,234	9,863	9,645	9,449	9,092	8,814
	2008	**2009**	**2010**	**2011**	**2012**	**2013**	
Heat Rate	8,859	8,741	8,571	8,897	8,547	8,537	

Source: QFER CEC-1304 Power Plant Data Reporting.

The data for this staff paper is 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

1 2013 Average Heat Rate = 8,537 Btu/kWh
2001 Average Heat Rate = 10,331 Btu/kWh
Percentage Change in Heat Rate = (10,331 – 8,537) / 10,331 = 17.4%

2 Annual figures differ from previous staff paper due to revisions and the addition of some units not previously reported under Quarterly Fuel and Energy Reporting regulations. California Code of Regulations, Title 20, Division 2, Chapter 3, Section 1304(a)(1)-(2).

California end users must report their generation, fuel, and water use for each calendar year to the Energy Commission. The Energy Commission compiles the data and posts it publicly on the Energy Commission's Energy Almanac website.[3] This is the third in a series of papers documenting the changes in thermal efficiency of gas-fired generation in California. [4]

Natural Gas Plant Categories and Capacities

The gas-fired power plants examined in this paper have been grouped into five categories based on a combination of duty cycles, vintage of the generating unit, and technology type.

A "combined-cycle" power generation block has a steam turbine that is combined with at least one combustion turbine. The higher fuel efficiency results from the ability to use the waste heat from the combustion turbine to produce steam for the steam turbine. For this report, combined-cycle power plants consist of those generating units constructed in the 2000s with a total plant capacity of 100 MW or more. These newer plants produce electricity with better heat rates than either stand-alone combustion turbines or steam turbines. In 2001, the 550 MW Sutter Energy Center and the 594 MW Los Medanos Energy Center facilities were the only combined-cycle power plants with this new technology; by 2013, California had 34 large combined-cycle plants totaling almost 20,000 MW in nameplate capacity.

"Aging" power plants are those plants built prior to 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 cleaner, more efficient combined-cycle turbine technology. There were 27 power plants in 2001 with an operational nameplate capacity of almost 20,000 MW. By 2013, there were still 19 operational aging power plants with a combined nameplate capacity of 15,850 MW. Closures included South Bay, Humboldt Bay, Potrero, Valley, Magnolia, Long Beach, Hunter's Point, and Contra Costa.

The "cogeneration" category consists of a mix of combustion turbines, combined-cycle units, and steam turbines; they typically have relatively high heat rates and high capacity factors.

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3 Energy Almanac. QFER CEC-1304 Power Plant Owner Reporting Database. June 2014. http://energyalmanac.ca.gov/electricity/web_qfer/.

4*Thermal Efficiency of Gas-Fired Generation in California*. California Energy Commission. CEC 200-2011-0008. < http://www.energy.ca.gov/publications/displayOneReport.php?pubNum=CEC-200-2011-008>.

Thermal Efficiency of Gas-Fired Generation in California: 2012 Update. California Energy Commission. CEC 200-2013-0002. < http://www.energy.ca.gov/publications/displayOneReport.php?pubNum=CEC-200-2013-002>.

Cogeneration plants, commonly referred to as *combined heat and power* (CHP) 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 injections to the electrical grid. Cogeneration plants tend to operate at higher average capacity factors 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 2013: 148 and 137, respectively. The majority of cogeneration plants in California are under 50 MW in size, often in the 1 MW to 10 MW range.

“Peaker” plants are 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. This is the only category of generating units grouped together based on their duty cycle. These plants typically use a fast-ramping, simple-cycle combustion turbine and are usually restricted in their total hours of operation on an annual basis by air quality and environmental regulations. There were 29 peaker plants identified in 2001; by 2013, the number of peaker plants had grown to 71.

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 prior to the 2000s that are not considered to be peakers, cogeneration, or aging. This category also includes combined-cycle plants composed of repurposed older gas and steam turbines, as well as fast-ramping, simple-cycle plants built to integrate intermittent renewable generation. There are fewer than 20 plants in this category for each year studied.

Table 2 summarizes in-state natural gas-fired electric generation in 2013, with breakouts for the five categories of natural gas-fired generation.

Table 2: California Natural Gas-Fired Power Plants Summary Statistics for 2013

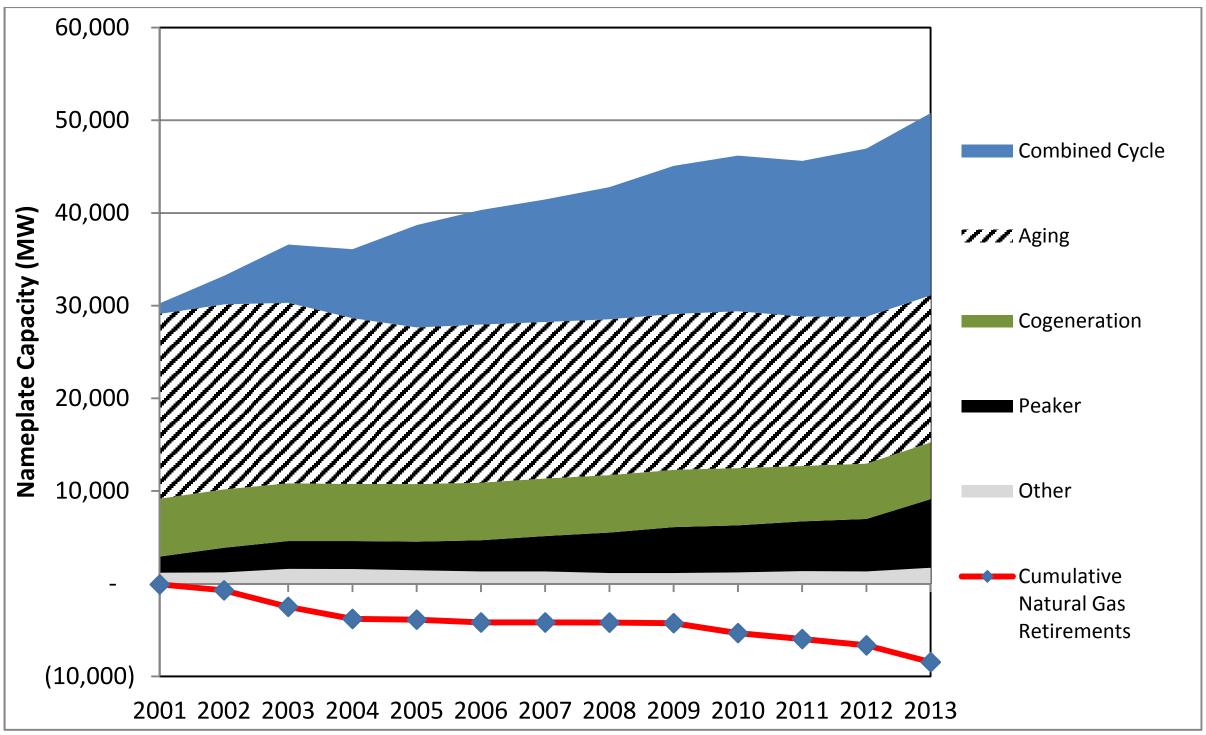
	Capacity (MW)	Share of Capacity	GWh	Share of GWh	Capacity Factor	Heat Rate (Btu/KWh)
Total Natural Gas	50,779	100.0%	129,766	100.0%	29.2%	8,537
Combined-Cycle	19,676	38.7%	87,361	67.3%	50.7%	7,205
Aging	15,851	31.2%	7,589	5.5%	5.5%	11,413
Cogeneration	6,117	12.0%	29,859	23.0%	55.7%	11,459*
Peaker	7,418	14.6%	3,310	2.6%	5.1%	10,268
Other	1,717	3.4%	1,647	1.3%	11.0%	9,504

Source: QFER CEC-1304 Power Plant Data Reporting.
*See paragraph on CHP above and Appendix A for more detail on cogeneration efficiency.

The total annual operational capacity of each category is shown in **Figure 1**. Over the past 13 years, combined-cycle, peaker, and other gas categories have experienced an overall increase in capacity, while cogeneration and aging capacities have declined. Cumulatively, by the close of 2013 nearly 8,500 MW of natural gas generation had been retired, as shown in **Figure 1** by a single line below the stacked-area graph.

These data have been compiled based on the attributes of the individual generating units within each power plant. In this study, generating units are assigned into 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 combined-cycle units. 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.

Trends in Heat Rates and Capacity Factors

Over the past 13 years, the thermal efficiency of California's gas-fired generation has improved by more than 17 percent. This is primarily due to an increase in generation from combined-cycle plants built since 2000 and reduced dependency on generation from aging power plants. If the cogeneration category is removed from this comparison, the efficiency gain over the past 13 years is 24 percent.[5] **Table 3** details the measured heat rates since 2001. Each category has a relatively consistent heat rate over the 13-year period, while the overall statewide average has improved each year.

Without accounting for the unique aspect of the dual output of steam and electricity, California's cogeneration plants appear to operate at relatively high, inefficient heat rates. Over the past 13 years, this heat rate has been near or above 11,000 Btu/kWh. However, given that these plants are also producing a useful thermal output, it is apparent that a heat rate that also accounted for the 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 useful output of steam and heat are beyond the scope of this paper. Lastly, the individual thermal quality requirements for each cogeneration industrial application may impose limitations on achievable electrical efficiency, thereby limiting potential improvements in the existing measured heat rate. **APPENDIX A** addresses this issue in more detail.

The capacity factors shown in **Table 4** give an overview of how often California's fleet of natural gas power plants operated each year. A *capacity factor* is the ratio of actual electricity production over a selected period divided by the maximum potential output over the same period. On average, California's combined-cycle and cogeneration plants operated at slightly more than 50 percent of their available permitted hours while aging, peaker, and other gas plants operated at 5 percent to 10 percent capacity factors. This difference in operation is to be expected based on an expectation of minimizing fuel costs by running California's more efficient combined-cycle plants and leaving the inefficient aging plants primarily for voltage support and local reliability. The newly constructed 828 MW simple-cycle Marsh Landing Generation Station included in the Other category resulted in the capacity factor dropping from 18 percent in 2012 to 11 percent in 2013. The weighted-average capacity factor for the entire state is about 30 percent for the period 2002 through 2013. The 2011 decrease in the combined-cycle capacity factor is directly attributable to increased hydroelectric generation that year. The discussion on hydroelectric and nuclear generation impacts later in this paper describes this more fully.

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5 2013 Average Heat Rate without Cogeneration = 7,664 Btu/kWh
2001 Average Heat Rate without Cogeneration = 10,046 Btu/kWh
Percentage Change in Heat Rate = (10,046 – 7,664) / 10,046 = 24%

Table 3: California Natural Gas-Fired Heat Rates for 2001 – 2013 (Btu/kWh)

	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Combined-Cycle	6,974	7,147	7,209	7,178	7,230	7,229	7,190	7,199	7,196	7,179	7,270	7,205	7,205
Aging	10,134	10,531	10,837	10,917	11,280	11,283	11,033	11,329	11,593	11,681	12,299	11,710	11,413
Cogeneration	10,934	10,961	10,986	11,177	11,272	11,234	11,149	11,300	11,154	10,972	11,020	11,052	11,459
Peaker	11,215	10,754	10,566	10,830	10,773	10,694	10,786	10,437	10,671	10,741	10,698	10,832	10,268
Other	10,142	9,528	10,174	9,841	9,845	9,979	9,940	9,996	10,469	9,867	9,537	9,438	9,504
State Average	10,331	10,234	9,863	9,645	9,449	9,092	8,814	8,859	8,741	8,571	8,897	8,547	8,537
State Average w/o Cogeneration	10,046	9,670	9,075	8,742	8,361	8,108	7,885	7,974	7,855	7,628	7,879	7,808	7,664

Source: QFER CEC-1304 Power Plant Data Reporting.

Table 4: California Natural Gas-Fired Power Plant Capacity Factors for 2001 – 2013

	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Combined-Cycle	54%	48%	48%	58%	44%	53%	62%	61%	54%	49%	37%	54%	51%
Aging	42%	21%	15%	16%	10%	9%	9%	10%	8%	4%	4%	7%	5%
Cogeneration	68%	73%	71%	72%	66%	63%	64%	63%	61%	59%	59%	56%	56%
Peaker	10%	5%	4%	4%	4%	3%	4%	4%	4%	3%	3%	5%	5%
Other	10%	10%	13%	14%	16%	14%	17%	17%	13%	14%	19%	18%	11%
State Average	44%	32%	29%	33%	28%	31%	34%	34%	31%	28%	24%	32%	29%

Source: QFER CEC-1304 Power Plant Data Reporting.

Natural Gas Generation

Natural gas is the dominant fuel source for electric generation in California in both nameplate capacity and total energy supplied. In 2013, nearly 51,000 MW of natural gas generation capacity supplied 44 percent (129,766 gigawatt-hours [GWh]) of California's total system energy needs for the year. Combined-cycle plants comprised 39 percent of total natural gas capacity and provided 67 percent (87,361 GWh) of the total energy from gas-fired generation categories. As mentioned, the combined-cycle plants operated at an average capacity factor of 51 percent and had an average heat rate of 7,205 Btu/kWh in higher heating value terms.

In contrast, aging power plants accounted for only 6 percent (7,589 GWh) of gas-fired electric generation but still held 31 percent of the state's total gas-fired capacity. (See **Figure 1**.) These aging plants operated at a 5 percent capacity factor in 2013, compared to a 42 percent capacity factor in 2001, with an average heat rate of 11,413 Btu/kWh. The low capacity factor indicates the primary value of these plants is in providing capacity for local reliability that may include voltage control, frequency response, and other ancillary services.[6] Control of voltage and frequency within a power system are essential to maintaining balance between generation and load. *Voltage control* refers to 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 refers to the ability to dispatch generation due to decreases in supply or increases in load within a power system.

Hydroelectric and Nuclear Generation Impacts

As shown in **Figure 2**, a sharp decline in generation from aging power plants after 2001 began a trend that continued throughout the decade as more modern combined-cycle plants were brought on-line. The total amount of gas-fired generation was particularly high in 2001 due to an extreme drought that affected California and Pacific Northwest hydroelectric generation. Total gas-fired generation increased markedly from 2005 as California's

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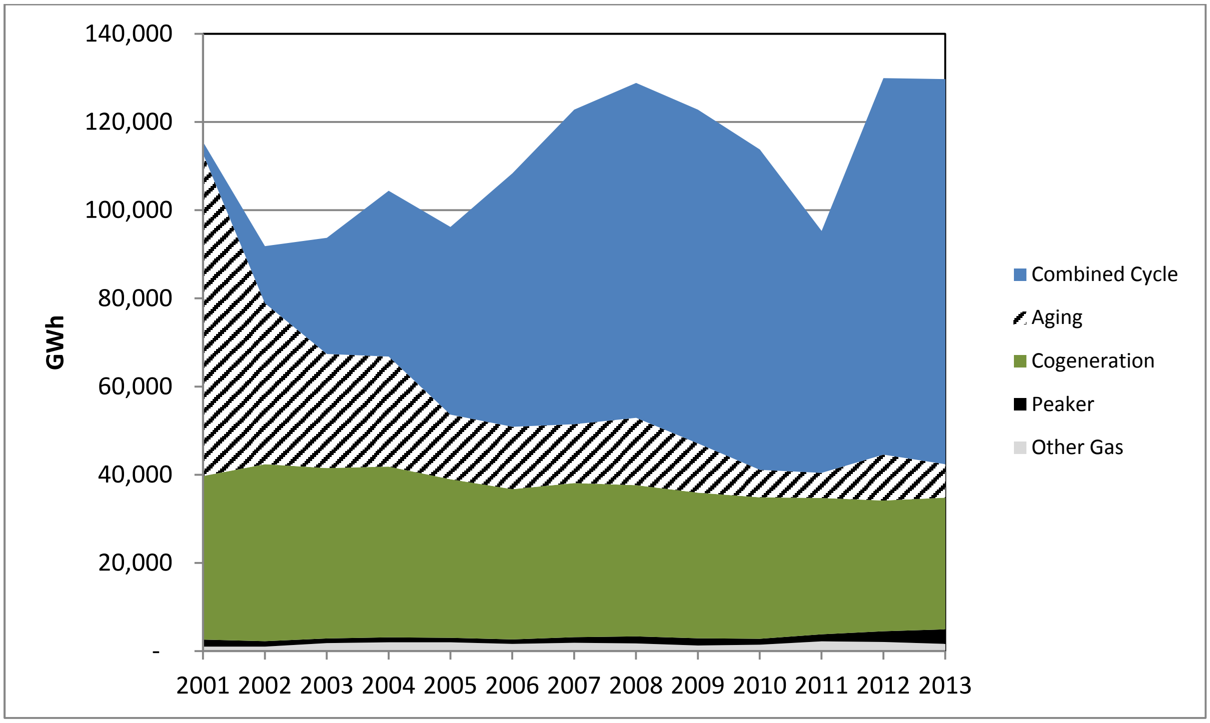
6 California Energy Commission. *The Role of Aging and Once-Through-Cooling Power Plants in California — An Update.* CEC-200-2009-018. See http://www.energy.ca.gov/2009publications/CEC-200-2009-018/CEC-200-2009-018.PDF.

economy grew, particularly during the 2007 and 2008 dry hydropower years in California. Generation from aging plants diminished as the economic recession took hold in 2009 and 2010.[7]

Figure 2: Natural Gas-Fired Electric Generation Directly Serving California



Source: QFER CEC-1304 Power Plant Data Reporting.

In 2011 there was a slight reversal in this trend due to the availability of abundant hydroelectric generation, the result of a wet hydrological year. Generally, when snowmelt and runoff is plentiful in California, hydroelectric energy is available during the spring and fall months at a much lower cost than natural gas. Therefore, in wet years natural gas-fired generation is "displaced" (reduced) by low-cost hydroelectric generation. The magnitude of available hydroelectric generation results in curtailments of natural gas-fired generation from the combined-cycle power plant fleet. With the exception of the cogeneration fleet, this category is the only one large enough to match the available hydroelectric generation.

7 Between 2001 and 2013, the level of direct coal-fired electricity imported from out-of-state sources dropped from 23,700 GWh to 11,824 GWh due primarily to the shutdown of Mohave Power Station in Laughlin, Nevada. This drop in coal imports has been largely made-up from increases in gas-fired generation. While this does not diminish the importance of assessing current levels of coal imports, it does help provide additional support for the realized efficiency improvements in California’s overall heat rates for its in-state natural gas power plants.

Cogeneration plants are unable to be displaced by hydroelectric availability due to the steady thermal requirements of the individual hosts.

In both 2012 and 2013, hydroelectric generation decreased significantly: down 36 percent in 2012 and another 10 percent in 2013. These declines were directly due to multiyear dry weather conditions, notwithstanding 2011. Where 2011 was characterized by a heavy and late-melting Sierra snowpack, statewide precipitation for winter 2012 was the third driest in 118 years, according to the National Climatic Data Center. By the end of 2013, California had its driest calendar year in recorded history with only 7.38 inches of precipitation, 15.13 inches below average. On January 17, 2014, Governor Brown officially declared the state to be in a drought. Energy Commission staff estimates hydroelectric generation from in-state generators for 2014 will be about 48 percent of the 1982 through 2013 average.

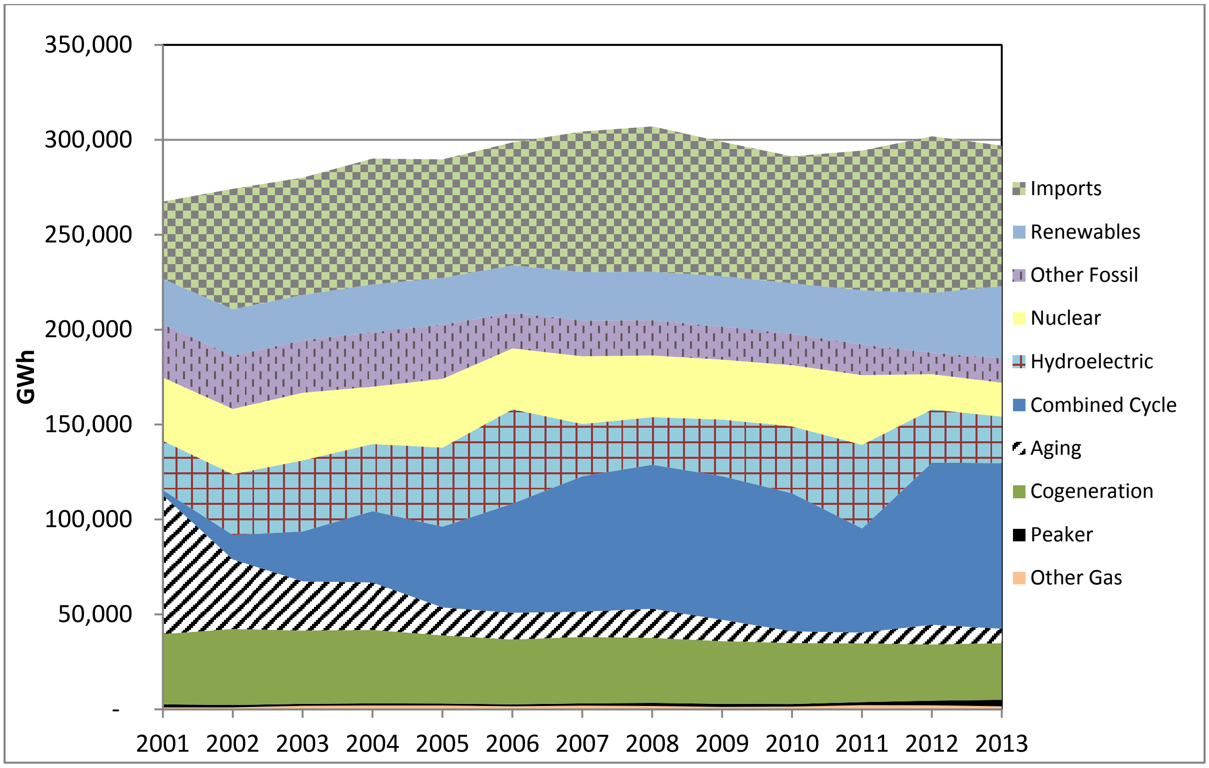
The loss of the San Onofre Nuclear Generation Station (SONGS) on January 31, 2012 due to leaking steam generator tubes resulted in increased generation from California's natural gas power plants. SONGS had a nameplate capacity of 2,254 MW and alone accounted for about 9 percent, or 18,000 GWh, of California's total in-state generation. Aging power plants almost doubled their generation from 5,691 GWh in 2011 to 10,433 GWh in 2012 to help make up for the loss. The combined-cycle fleet also ramped up generation to 85,397 GWh from 54,878 GWh the year before. Additional new combined-cycle plants came on-line in 2012 and 2013, reducing California's reliance on aging plants to 2010 levels by the end of 2013. During these past two years substantial capacity additions for wind and solar generation in California helped to replace the lost generation capacity from the closure of SONGS.

Accordingly, lower in-state hydroelectric availability and the closure of SONGS were the primary reasons for the 36 percent increase in natural gas generation in 2012 and continued similar levels of natural gas-fired generation in 2013.

California's Total System Power

Figure 3 provides 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, commonly referred to as *total system power*. The total system power chart illustrates the contribution of each power generation category toward the state's Total System Power mix. The interplay between the availability of hydroelectric and nuclear energy and the associated impacts on natural gas generation is made clear. Imports account for about 33 percent of California's Total System Power mix and play a large role in shaping the state's overall efficiency. Part of this imported energy is composed long-term contracts by California utilities with out-of-state power plants, referred to as *specific claims* by utilities. The remainder of the imports category is from spot market purchases, referred to as *unspecified power*. Unspecified power is power that cannot be directly sourced back to the originating power plant.

Figure 3: California Total System Power

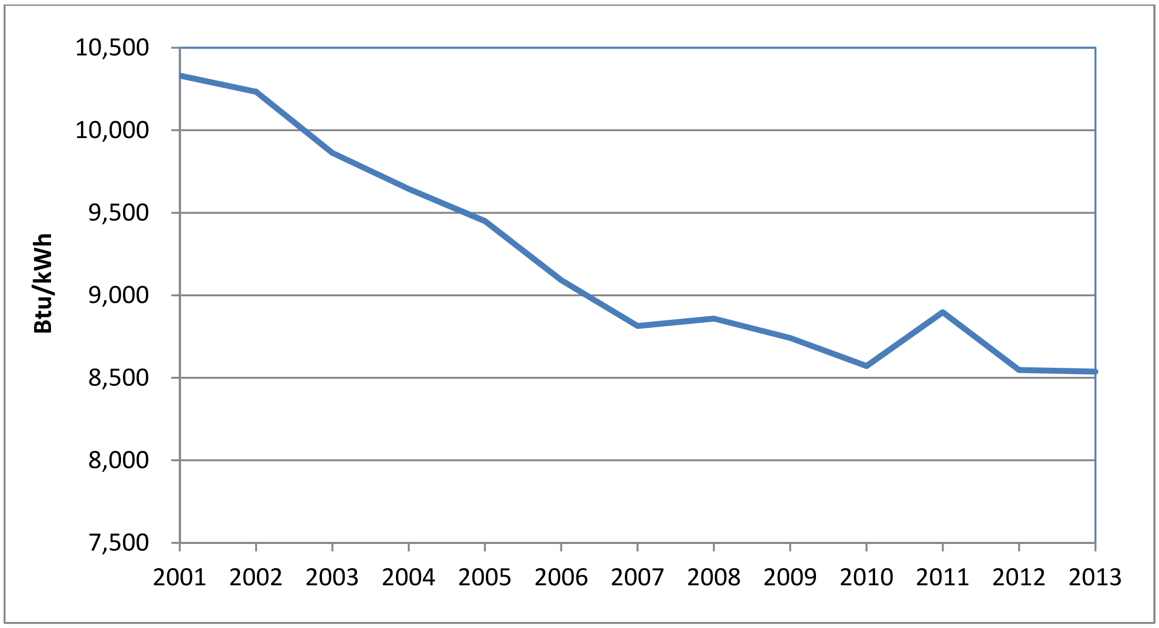


Source: QFER CEC-1304 Power Plant Data Reporting.

The supporting regulations for auditing specific claims are being replaced by efforts to codify Senate Bill X1-2 (Simitian, Chapter 1, Statutes of 2011), signed by Governor Edmund G. Brown Jr. in April 2011. Senate Bill X1-2 requires all electricity retailers in the state to adopt the new Renewables Portfolio Standard goal of 20 percent of retail sales from renewables by the end of 2013, 25 percent by the end of 2016, and 33 percent by the end of 2020, not just investor-owned utilities. Since 2009, unspecified power accounts for about 50 percent of California's annual imports, or about 15 percent of the state's Total System Power mix. It is expected that Senate Bill X1-2 will help clarify the composition of the unspecified imports through changes in reporting regulations for California utilities importing power and thereby detailing the magnitude of any existing unspecified power. Unspecified power at that time should be solely composed of power that has either lost the ability to be traced to a primary source due to the structure of the electricity marketplace or if the renewable energy credits once associated with the power were transferred separately. Energy sold separately from its renewable energy credits is referred to as *null power.*

Figure 4 shows how the collective average heat rate for gas-fired generation in California has improved over the decade. This trend has been consistent, and the efficiency gains have been cumulative. These gains in power plant efficiency, as measured by heat rates, result in direct reductions in greenhouse gas (GHG) emissions. The heat rate is directly proportional to GHG emissions. As may be judged by the slope of the trend line in **Figure 4**, the greatest efficiency gains occurred from 2002 through 2003 and from 2005 through 2007, when the majority of combined-cycle plants began commercial service. The displacement of gas-fired generation by abundant hydroelectric power caused the slight increase in the heat rate for 2011. Accordingly, natural gas units operated fewer hours at more inefficient fuel consumption levels over the year. By 2012, the downward trend in the statewide heat rate resumed with combined-cycle heat rates flattening out at 7,205 Btu/kWh, resulting in an average heat rate of 8,537 Btu/kWh in 2013. The impact of the drought resulted in higher capacity factors, thereby increasing fuel-burn efficiency, but at the additional cost of increased overall GHG emissions from the natural gas power plant fleet.

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



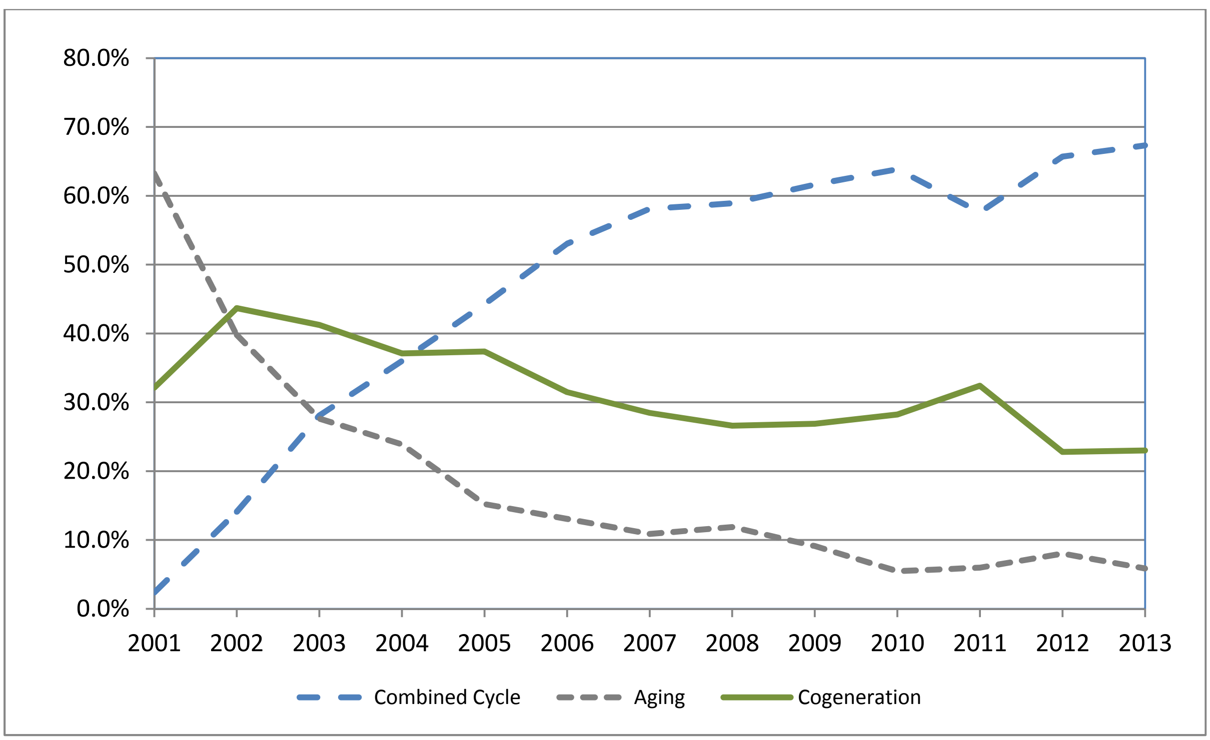
Source: QFER CEC-1304 Power Plant Data Reporting.

The data reflected in **Figure 2, Figure 3,** and **Figure 4,** when taken together, suggest that the successful development of combined-cycle plants since 2001 is the primary reason for the improvement in California's systemwide heat rate. While the average heat rate for combined-cycle plants in 2013 was 7,205 Btu/kWh, the long-run limit on combined-cycle efficiency is generally held to be about 6,300 Btu/kWh. Under actual operating conditions, 6,600 Btu/kWh – 6,700 Btu/kWh on average might be seen from these resources, potentially further reducing California's natural gas heat rate from 8,537 Btu/kWh in 2013.

There are several factors, however, that will affect these reductions. For example, **Table 5** and **Table 6** exhibit the increased reliance upon aging power plants in 2012 due to the SONGS outage compounded by a dry hydro year with higher generation and fuel usage levels that were comparable to 2009 levels. As intermittent renewable generation projects are added to the resource mix, the gas plant fleet is increasingly going to be tasked with ramping generation up and down over a wider range of conditions, as well as cycling on and off daily, to compensate for the fluctuations the variable wind and solar resources create. Adding this functionality to new gas-fired generation comes at the cost of efficiency in two areas. The full load heat rates of resources operating in this manner are often higher than for combined-cycle units designed to be operated at fixed levels of output. In addition, the operation of these resources at partial load, while not prohibitively inefficient, does result in a relative loss of efficiency (for example, a higher heat rate).

Over the past 13 years, efficiency improvements in the state's natural gas fleet of power plants have provided a direct reduction in GHG emissions from what would have been the case if combined-cycle power plants had not been introduced to the power mix. As shown in both **Figure 5** and **Table 5**, power generated from combined-cycle plants has surpassed (or displaced) the peak generation from aging power plants. In 2001, aging power plants generated 73,041 GWh, while combined-cycle plants generated only 2,730 GWh. By 2013, combined-cycle gas plants generated 87,361 GWh while aging plants generated 7,589 GWh, a complete reversal in roles from 2001. The total capacity of combined-cycle plants in 2013 equaled the total capacity of California's aging plants in 2001 at slightly more than 19,500 MW.

Figure 5: Trends in Gas-Fired Output by Plant Type



Source: QFER CEC-1304 Power Plant Data Reporting.

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
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
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
Cogeneration	37,088	40,122	38,650	38,733	35,976	34,104	34,942	34,276	33,003	32,109	30,897	29,620	29,859
Peaker	1,568	1,237	1,019	1,130	1,002	1,014	1,250	1,586	1,649	1,313	1,607	2,431	3,310
Other	1,040	1,029	1,842	2,009	2,017	1,631	1,916	1,768	1,271	1,475	2,233	2,098	1,647
State Total	115,465	91,876	93,734	104,417	96,215	108,369	122,812	128,873	122,830	113,767	95,305	129,978	129,766

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
Combined Cycle	19,036	92,581	189,850	269,908	307,828	415,525	513,084	546,692	544,811	521,541	398,968	615,287	629,449
Aging	740,199	384,769	280,521	272,272	165,192	159,512	147,256	173,401	129,845	72,659	69,993	122,167	86,616
Cogeneration	405,520	439,770	424,622	432,905	405,512	383,108	389,574	387,332	368,120	352,288	340,493	327,371	342,139
Peaker	17,580	13,302	10,770	12,233	10,798	10,849	13,487	16,554	17,602	14,105	17,193	26,328	33,989
Other	10,543	9,805	18,745	19,771	19,855	16,278	19,044	17,670	13,307	14,558	21,292	19,803	15,652
State Total	1,192,879	940,226	924,508	1,007,090	909,184	985,272	1,082,444	1,141,649	1,073,685	975,151	847,939	1,110,956	1,107,845

Source: QFER CEC-1304 Power Plant Data Reporting.

Conclusion

California has experienced a significant improvement in the thermal efficiency of its in-state natural gas power plants over the last 13 years. From 2001 to 2013, thermal efficiency has improved 17 percent. This improvement in efficiency is due to the increased reliance upon new combined-cycle power plants that are operating at a 51 percent capacity factor. By contrast, aging power plants are operating at a 5 percent capacity factor, down from 42 percent in 2001. California has benefitted from this improved thermal efficiency in terms of GHG emission reductions, although the closure of SONGS in January 2012 and the recent drought have somewhat dampened this effect temporarily. 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).

APPENDIX A: Cogeneration Efficiency

Cogeneration or CHP facilities are difficult to compare to other sources of generation due to the multiple forms of energy output. There are two common methods that are used to determine metrics to evaluate CHP systems: total system efficiency, and effective electrical efficiency.

The calculation for total system efficiency ($Efftotal$) of a CHP system sums the net useful electric power output (P) and the net useful thermal output (Q) divided by the total fuel input (F).

$$Eff_{total} = \frac{P + Q}{F}$$

This metric does not differentiate between the value of power output and thermal output; it treats them as additive properties with the same relative value.

The calculation for effective electrical efficiency (Eff_{elect}) removes the thermal fuel component (Q/α) from the total fuel input (F), based on an assumed thermal efficiency of the displaced boiler (α), leaving a ratio of energy divided by fuel, given as a heat rate.

$$Eff_{elect} = \frac{P}{F - (Q/\alpha)}$$

Many CHP systems are designed to meet a host site's unique power and thermal demand characteristics. As a result, a truly accurate measure of a CHP system's efficiency may require additional information than what has been described.

Under the *Quarterly Fuel and Energy Reporting Regulations*, the Energy Commission collects net electric generation, fuel use, and sales of electricity and thermal energy to end users.[8]

The collected thermal energy data is improper to use in these calculations because thermal energy sales are not equivalent to useful thermal energy. They may be equivalent when all thermal energy is sold to end users, but not when the CHP system owner uses some or all of the thermal energy.

In addition, determining an effective electrical heat rate requires making assumptions about displaced boiler efficiency. Boiler efficiency varies depending on fuel type and heat quality. Boiler efficiencies are informed by data, but ultimately debated, negotiated, and agreed-upon numbers. They are not universally accepted, and making those assumptions is outside the scope of this paper.

8 Quarterly Fuel and Energy Reporting Regulations. California Code of Regulations, Title 20, Division 2, Chapter 3, Section 1304(a)(2).