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Thermal Efficiency of Gas-Fired Generation in California: 2012 Update

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ABSTRACT

This staff paper describes general trends in natural gas-fired generation in California from 2001 through 2011. Over this 11-year period, California's gas-fired generation has seen thermal efficiency improvements of more than 21 percent. This improvement is due to the increased reliance upon combined cycle power plants, which are currently operating at a 37 percent capacity factor. By contrast, aging power plants now operate at a 4 percent capacity factor, compared to 43 percent capacity factor in 2001. The successful development of new combined cycle plants is the primary reason for the improvement in California's systemwide heat rate. The thermal efficiency of the state's portfolio of natural gas power plants offers significant reductions in greenhouse gas emissions compared to 11 years ago.

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

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Discussion

This staff paper updates some general trends in natural gas-fired generation in California from 2001 through 2011.[1] Over this 11-year period, the thermal efficiency of California's gas-fired generation has improved more than 21 percent.[2] An increase in generation from newer combined cycle plants and a reduced dependence on generation from aging power plants are the chief reasons.

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 Btu [British thermal units]) to produce one unit of energy (measured kWh [kilowatt hour]). 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.

The average heat rate of all non-cogeneration forms of gas-fired generation has declined from 9,997 to 7,855 Btu/kWh (British thermal units per kilowatt hour) from 2001 to 2011, as shown in **Table 1**. The slight increase in heat rate from 2010 to 2011 resulted from the displacement of California's most efficient combined cycle gas plants by abundant hydroelectric generation, the result of a wet hydrological year in 2011.

Table 1: California Natural Gas-Fired Heat Rates for 2001–2011 (Btu/kWh)[3]

	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Total Gas	9,997	9,645	9,080	8,726	8,393	8,111	7,890	7,972	7,858	7,596	7,855

Source: QFER CEC-1304 Power Plant Data Reporting.

A plant's capacity factor is the ratio of the electricity produced over a period divided by the amount of electricity the power plant could have produced if it had been operated at its

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1 This study is not intended to address the impacts on the statewide electric system's inertia component that is occurring due to the changeover from aging steam turbines to newer combined cycle plants and the growth in renewable generation. System inertia refers to the rotating mass of electrical generation and is a measure of an electrical system's ability to absorb fluctuations in frequency. Generally, the lower the system's inertia, the more susceptible the electrical system is to disruptions and outages. In this context, inertia is a measure of an electrical system's resistance to failures.

2 2011 Annual Average Heat Rate = 7,855 Btu/kWh
2001 Annual Average Heat Rate = 9,997 Btu/kWh
Percentage Change in Heat Rate = (9,997 – 7,855) / 9,997 = 21.4 percent.

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

maximum permitted capacity for the same period of measurement. The capacity factor gives a quick overview of how often a plant operated over time. The capacity factor for all gas-fired generation decreased from 28 percent in 2010 to 24 percent in 2011.

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 generator unit, and technology type.

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 based on a 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. There were 34 peaker plants identified in 2001; by 2011, the number of peaker plants had grown to 69.

Aging power plants are those plants built before 1980 and composed almost exclusively of steam turbines that use once-through-cooling (OTC) technology. Given air quality and environmental concerns, aging power plants are currently being phased out or repowered with cleaner, more efficient combined cycle turbine technology. The number of aging power plants has fallen from 26 to 19 as of 2011. Closures included South Bay, Humboldt Bay, Potrero, Valley, Magnolia, Long Beach, and Hunter's Point.

The combined cycle category is composed of those generating units constructed since the late 1990s with a total plant capacity of 100 megawatts (MW) or more. A combined cycle plant has a steam turbine that is integrated with at least one combustion turbine. Its higher fuel efficiency results from the ability to use the waste heat from the combustion turbine to produce steam for the steam turbine. These newer combined cycle plants produce electricity with better heat rates than either stand-alone combustion turbines or steam turbines. In 2001 there were only 5 combined cycle plants with this new technology; by 2011, California had 29 new combined cycle plants.[4]

The cogeneration category is composed of a mix of combustion turbines, combined cycle units, and steam turbines; they typically have relatively high heat rates. Cogeneration plants, commonly referred to as combined heat and power or CHP plants, produce heat for an onsite or nearby dedicated thermal host, such as a cannery or college campus, and electricity either for onsite industrial use or wholesale injections to the electrical grid. Heat rates measure the conversion of chemical energy in natural gas to electrical energy but do not incorporate a credit for the beneficial industrial use of the waste steam. This category is not included in the overall heat rate calculation due to the difficulty of assessing the efficiency of the thermal host. Appendix B addresses this issue in more detail. The number of cogeneration plants has remained relatively constant from 2001 through 2011: 151 and 143, respectively. The majority of cogeneration plants in California are under 50 MW in size, often in the 1-10 MW range.

4 The previous report listed 30 combined cycle plants as of 2010. This inadvertently included a combined cycle unit that was rated at less than 100 MW.

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 mid-1990s that are not considered to be peakers, cogeneration, or aging. In particular, Huntington Beach units 3 and 4 have a combined capacity of 450 MW and account for almost half of the total capacity in this category. These two units are scheduled to be converted to *synchronous condensers* before August 2013 with no net change in capacity. There are about 12 plants in this category for each year studied.

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 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.

Natural gas generation fell significantly in 2011 compared to 2010, from 116,750 gigawatt hours (GWh) to 95,775 GWh. The three primary reasons for the decline in natural gas-based generation were mild temperatures, significant increases in hydroelectric generation from both in-state and out-of-state power plants, and lingering effects from the 2007–2009 economic recession.[5]

Temperatures in California during 2011 were lower than normal during the spring, near normal during the summer, and above normal during both the fall and winter, resulting in modest demand reductions in electricity consumption.[6] By design, California's electric generation system delivers electricity quickly to match peak air-conditioning load conditions in the summer. Mild temperatures reduced the need for air conditioning in 2011. Above-average precipitation in the Pacific Northwest resulted in a 12 percent increase in imported energy. Between March and May 2011, Oregon and Washington experienced their wettest periods in the last 116 and 117 years, respectively.[7]

In-state hydroelectric generation showed a significant increase of 25 percent from 2010, growing from 34,308 GWh in 2010 to 42,727 GWh in 2011,[8] as California experienced one of its wettest hydrological years. After three relatively dry years, statewide precipitation during the 2010 Water Year (ending September 30, 2010) was 105 percent of average.

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5 Determination of the December 2007 Peak in Economic Activity: http://www.nber.org/cycles/dec2008.pdf.

6 State of the Climate National Overview Annual 2011: http://www.ncdc.noaa.gov/sotc/national/2011/13.

7 United States Had Most Extreme Spring on Record for Precipitation: http://www.worldweatherpost.com/2011/06/14/u-s-had-most-extreme-spring-on-record-for-precipitation/#.UBggpKDhfHM.

8 California Electrical Energy Generation, 1997 to 2011: http://energyalmanac.ca.gov/electricity/electricity_generation.html.

Precipitation during the 2011 Water Year was 135 percent of average, and runoff was 146 percent of average. Though January 2011 was remarkably dry, the months of March and May were extremely wet with peak snowmelt in early July. As a result, in-state hydroelectric generation in 2011 was 127 percent of average compared to 101 percent in 2010.

When snowmelt and runoff are plentiful, California's hydroelectricity generally is less expensive to purchase than electricity generated by plants using natural gas-fired generation. Therefore, usage of natural gas-fired generation is reduced (*displaced*). This is especially so during the spring and fall months and during off-peak summer hours (afternoon and early evening hours).

Finally, reduced statewide demand for electricity also impacted the output from gas-fired generation. The short-term peak demand forecasts for 2011 and 2012 were 5 percent less than originally forecasted in the Pacific Gas and Electric Company (PG&E), Southern California Edison (SCE), and San Diego Gas & Electric Company (SDG&E) service territories, suggesting that California was still recovering from the effects of the economic recession.[9]

Table 2 summarizes in-state natural gas-fired electric generation in 2011 with breakouts for the five categories of natural gas-fired generation.

9 Table 1: Comparison of Revised 1 in 10 and 2009 IEPR Peak Demand Forecasts (Megawatts), 2011 and 2012: http://www.energy.ca.gov/2010publications/CEC-200-2010-011/CEC-200-2010-011-SD.pdf.

Table 2: California Natural Gas-Fired Power Plants Summary Statistics for 2011

	Capacity (MW)	Share of Capacity	GWh	Share of GWh	Capacity Factor	Heat Rate (Btu/KWh)[1]
Total Gas	45,850	100.0%	95,775	100.0%	23.8%	7,855
Combined Cycle Plants [2]	17,163	37.4%	55,368	57.8%	36.8%	7,303
Aging Plants [3]	15,964	34.2%	5,679	5.9%	4.1%	11,989
Peaker Plants [4]	5,801	12.7%	1,654	1.7%	3.3%	10,705
Cogeneration [5]	6,070	13.2%	31,537	32.9%	59.3%	N/A
Other [6]	1,121	2.4%	1,538	1.6%	15.7%	9,378

Source: QFER CEC-1304 Power Plant Data Reporting. Values may not add due to rounding.

1. All Btu's in this paper are in higher heating values (HHV).
2. Combined cycle plants 100 MW and larger built since mid-1990s.
3. Power plants identified as aging were built before the 1980s.
4. Peaker plants are identified as operating less than 10 percent of the time, used primarily to meet peak load conditions.
5. Includes CHP plants using both combined cycle and simple cycle technologies. Appendix B addresses the different treatment of heat rate for this category.
6. Includes all remaining natural gas plants not falling into any of the above-identified categories such as internal combustion generators and plants built in the 1970s, 1980s, and 1990s.

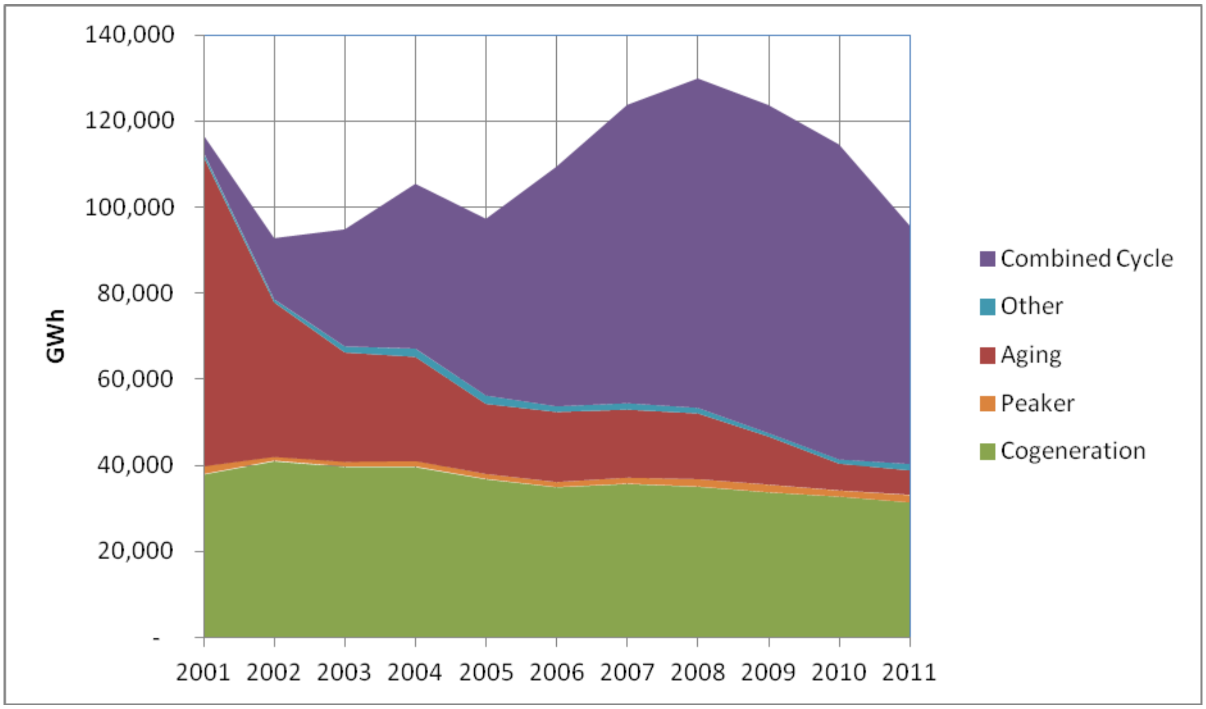
By capacity, about 37 percent of the fleet of gas plants is composed of combined cycle units built since the 2000–2001 energy crisis. However, these new combined cycle plants provided 58 percent of the energy from all gas-fired generation categories in 2011. Combined cycle units operated at an average capacity factor of 37 percent and had an average heat rate of 7,303 Btu/kWh.

In contrast, the group of aging power plants comprised 34 percent of all gas-fired capacity but contributed only 6 percent of all electric generation from natural gas in 2011. These aging plants (more than 35 years old) operated at a 4 percent capacity factor and had an average heat rate of 11,989 Btu/kWh.

As shown in **Figure 1**, the sharp decline in generation from aging power plants after 2001 began a trend that continued throughout the decade as more combined-cycle plants came on-line. Total amounts of gas-fired generation were particularly high in 2001 due to an extreme drought that year affecting California and Pacific Northwest hydro generation. Total gas-fired generation increased markedly from 2005 as the California economy grew, and particularly during 2007 and 2008 as those were dry hydropower years in California. Generation from aging plants held flat during the recent drought but continued to diminish as the economic recession took hold in 2009 and 2010.[10]

10 Between 2001 and 2011, the level of coal-fired electricity imported from out-of-state sources dropped from 23,700 GWh to 13,032 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

Figure 1: Total Gas-Fired Electric Generation



Source: QFER CEC-1304 Power Plant Data Reporting.

Combining the total energy produced by source (**Figure 1**) with the measured heat rates (**Table 2**) allows a combined average heat rate for California's natural gas-fired generation to be calculated.

Figure 2 shows how average heat rates for gas-fired generation in California have improved over the decade. This trend has been consistent with the exception of 2011. The upward slope of the average heat rate in 2011 was the result of a significantly reduced output from combined cycle plants due to the availability of hydroelectric power. As may be judged by the slope of the trend line in **Figure 2**, 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 increase in the average heat rate from 2010 to 2011 is a result of aging generation having a larger proportional share of total gas-fired generation compared to combined cycle generation. Gains in power plant efficiency, as measured by lower heat rates, result in direct reductions in greenhouse gas (GHG) emissions as the energy in each millions of British thermal units (MMBtu) of natural gas is able to produce

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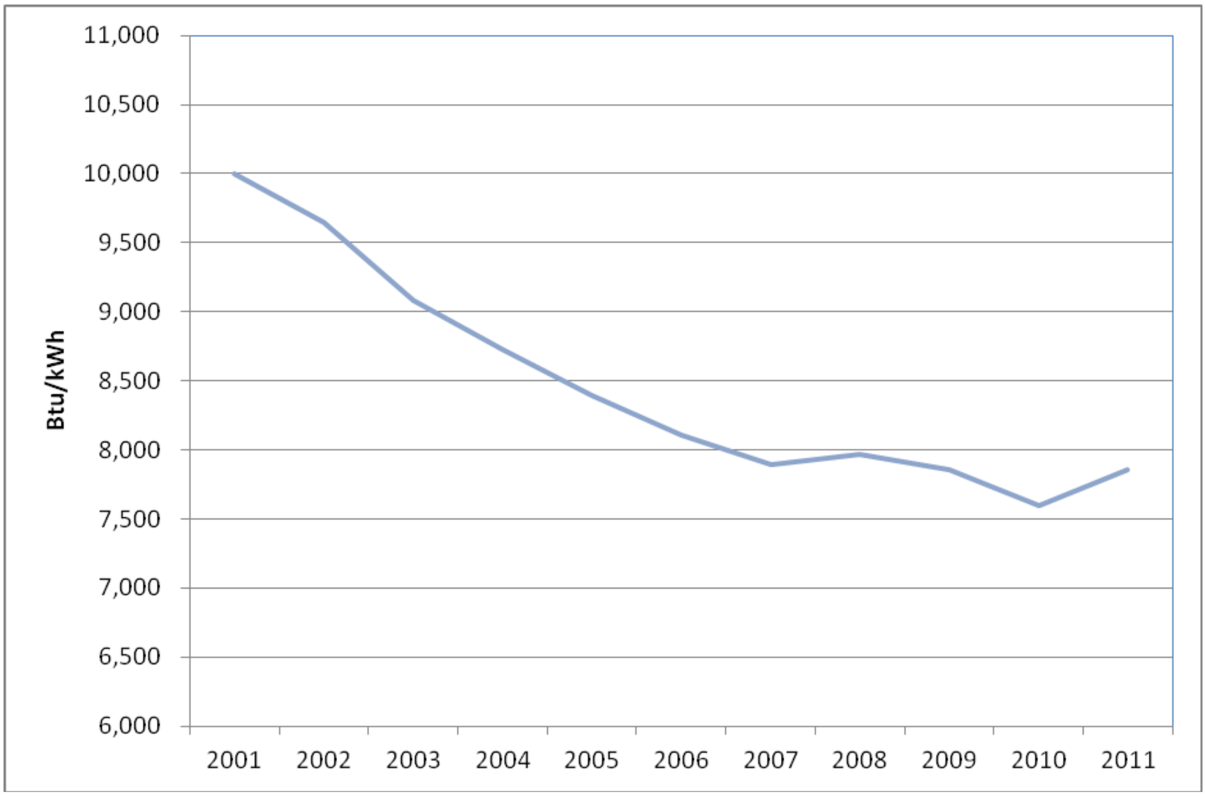
generation. While this does not diminish the importance of assessing current levels of coal imports, it does help provide additional support for the realized efficiency improvements in California's overall heat rates for its in-state natural gas power plants.

more electricity in the high efficiency combined cycle plants. Accordingly, the heat rate is directly proportional to GHG emissions.

The data reflected in **Figure 1** and **Figure 2** argue strongly that the successful development of new combined cycle plants since 2001 is the primary reason for the improvement in California's system-wide heat rate. The average heat rate for combined cycle plants in 2011 was 7,303 Btu/kWh, and the long-run limit on combined cycle efficiency is generally held to be about 6,300 Btu/kWh. Under real world operating conditions, 6,600–6,700 Btu/kWh on average might be seen from these resources, thus further reducing the system heat rate that was 7,855 Btu/kWh in 2011.

Figure 2: Gas-Fired Heat Rates for Electric Generation



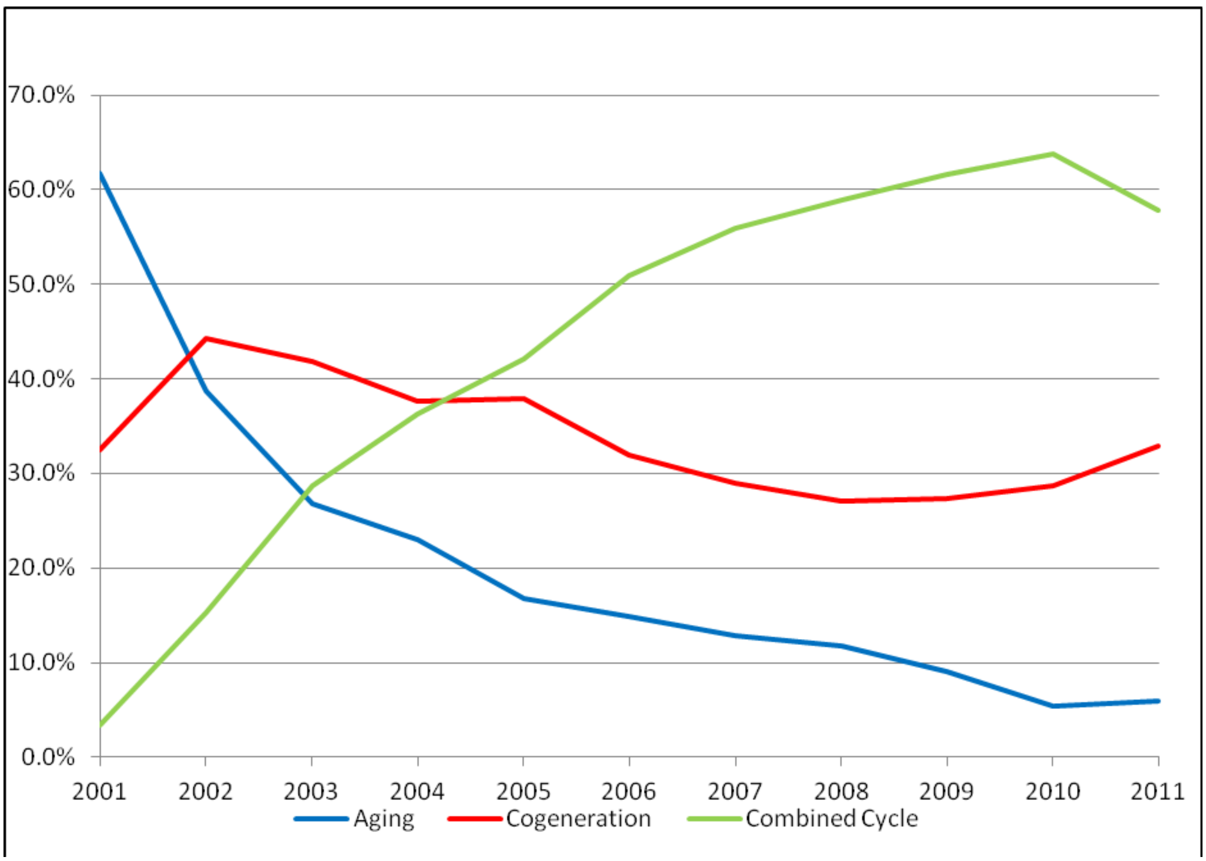
Source: QFER CEC-1304 Power Plant Data Reporting.

Note: Average heat rates do not include cogeneration.

Several factors will mitigate against such reductions in California's average heat rate. 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 new intermittent resource generation supply and availability. The *ramp rate* is a measurement of the rate of change in output of a power plant and is typically used in reference to the ability of a power plant to meet fluctuating loads. Adding this functionality to new gas-fired generation comes at the cost of efficiency in two areas. The full-load heat rates of such resources often exceed recently built combined cycle plants that are designed and intended to be operated at fixed levels of output. In addition, partial load operation of these resources, while not prohibitively inefficient, does result in a relative loss of efficiency (for example, a higher heat rate). The development of carbon sequestration technologies (*zero-carbon gas*) such as underground sequestration of carbon dioxide in geologic formations will occur only in conjunction with diverting more energy produced from serving customer load to powering on-site sequestration equipment (self-service or *parasitic* loads). The energy required for carbon sequestration will reduce amounts of net generation for load, thus increasing the net heat rate of the facility.

As stated, efficiency improvements offer a direct reduction in GHG emissions. Newer combined cycle plants have helped contribute to this reduction. As shown in both **Figure 3** and **Table 3**, power generated by combined cycle plants over the past 11 years has come very close to completely replacing (or displacing) the total output from aging power plants. In 2001, aging power plants generated 72,098 GWh while combined cycle plants generated only 3,969 GWh. Fast forward to 2010 and the combined cycle gas plants generated 73,137 GWh while aging plants generated 6,216 GWh – a near complete reversal in roles.

Figure 3: Trends in Gas-Fired Generation Output by Plant Type



Source: QFER CEC-1304 Power Plant Data Reporting.

Despite the recent decline in total gas-fired generation for 2011, as shown in **Table 3**, the average heat rate of the combined cycle and aging categories improved significantly from 9,925 to 7,732 Btu/kWh over the past 11 years.[11] The decline in gas-fired generation in 2011 was due to a 25 percent increase in California's hydroelectric generation. The state's hydroelectric generation fulfills a variety of roles, including both peaking reserve capacity and load-following capacity accompanied by extremely low production costs and near-zero air emissions. The result is a direct displacement of gas-fired combined cycle and aging generation when hydropower is available. [12] Cogeneration does not lend itself to being displaced because it has an onsite thermal host. Peaker combustion turbines continued to provide similar levels of service in 2011. Peakers are generally operated for voltage and frequency support to meet high load periods in a local distribution area, a role not always able to be fulfilled by lower cost hydropower.

Table 3: Electric Generation From California's Natural Gas-Fired Power Plants (GWh)

	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Total Gas	116,750	92,837	94,892	105,464	97,336	109,453	123,791	129,915	123,748	114,598	95,775
Combined-Cycle	3,969	14,172	27,166	38,249	41,030	55,657	69,273	76,478	76,151	73,137	55,368
Aging	72,098	35,971	25,487	24,270	16,309	16,314	15,847	15,303	11,193	6,216	5,679
Peakers	1,810	953	1,086	1,311	1,139	1,131	1,351	1,673	1,711	1,361	1,654
Cogeneration	37,993	41,045	39,746	39,714	36,898	35,031	35,817	35,158	33,854	32,871	31,537
Other	880	695	1,407	1,920	1,960	1,319	1,503	1,303	840	1,013	1,538

Source: QFER CEC-1304 Power Plant Data Reporting.

Table 4 details the 11-year history of heat rates for each category of gas-fired generation, except cogeneration. The displacement of gas-fired generation due to hydropower availability resulted in higher heat rates across the aging and combined cycle categories in 2011. Peakers maintained a relatively consistent heat rate over the past five years. As stated, heat rates are not able to be determined for the cogeneration category. Means of measuring efficiency for the cogeneration category are addressed in Appendix B. There is an additional difficulty in assessing potential efficiency gains related to the output of both steam and

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11 2001 Fuel Use by Combined Cycle + Aging Plants = (31 + 724) = 755 million MMBtu
2001 Generation by Combined Cycle + Aging Plants = (3,969 + 72,098) = 76,067 GWh
2001 Heat Rate = (755* 1,000,000) / 76,067= 9,925 Btu/kWh
2011 Fuel Use by Combined Cycle + Aging Plants = (404 + 68) = 472 million MMBtu
2011 Generation by Combined Cycle + Aging Plants = (55,368 + 5,679) = 61,046 GWh
2011 Heat Rate = (472 * 1,000,000) / 61,046 = 7,732 Btu/kWh

12 California Hydropower System: Energy and Environment, http://www.energy.ca.gov/reports/2003-10-30_100-03-018.PDF.

electricity as thermal quality requirements for industrial applications may impose limitations on achievable electrical efficiency. The data required to determine potential efficiency gains for cogeneration are beyond the scope of this paper.

Table 4: Heat Rates for California's Gas-Fired Power Plants (Btu/kWh)

	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Total Gas	9,997	9,645	9,080	8,726	8,393	8,111	7,890	7,972	7,858	7,596	7,855
Combined Cycle	7,844	7,379	7,310	7,223	7,302	7,261	7,213	7,217	7,224	7,195	7,303
Aging	10,036	10,474	10,822	10,859	10,703	10,673	10,409	11,327	11,590	11,268	11,989
Peakers	12,556	10,957	11,311	11,149	11,155	10,956	10,972	10,586	10,761	10,802	10,705
Other	11,273	11,182	9,998	10,041	10,393	9,825	9,749	9,553	9,710	9,737	9,378

Source: QFER CEC-1304 Power Plant Data Reporting.

Table 5 details the natural gas fuel use by California power plants. Total fuel usage from both combined cycle and aging categories fell by 38 percent from 2001 to 2011, from 755 to 472 MMBtu, respectively. Fuel usage by cogeneration plants decreased by 15 percent over this 11-year time frame. The average capacity factor decreased by 13 percent over this period indicating that some cogeneration plants were also able to reduce their steam output to their thermal hosts.

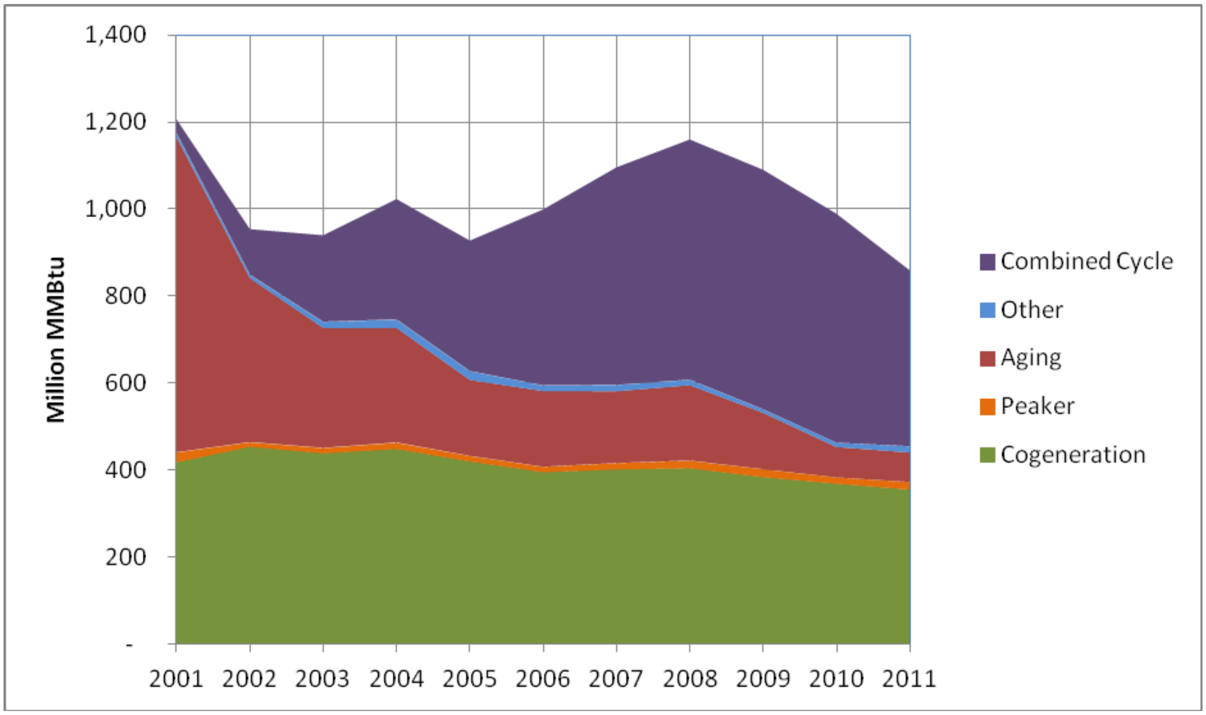
Table 5: Natural Gas Fuel Use by California's Power Plants (Million MMBtu)

	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Total Gas	1,205	953	939	1,022	927	998	1,095	1,159	1,090	989	859
Combined Cycle	31	105	199	276	300	404	500	552	550	526	404
Aging	724	377	276	264	175	174	165	173	130	70	68
Peakers	23	10	12	15	13	12	15	18	18	15	18
Cogeneration	418	453	438	448	419	395	401	404	383	368	354
Other	10	8	14	19	20	13	15	12	8	10	14

Source: QFER CEC-1304 Power Plant Data Reporting.

Figure 4 highlights the large reduction in fuel usage over the past 11 years by aging power plants and the relative constant fuel consumption by cogeneration plants in the state. The impact on total fuel usage from the peaker plant category is relatively small but consistent over the past 11 years, accounting for roughly 1 to 2 percent of total natural gas use each year. The combined cycle category continued to dominate fuel usage, although its level dropped to levels similar to the cogeneration category in 2011. A complete summary of share of generation (**Table A-1**), annual capacity (**Table A-2**), and capacity factors (**Table A-3**) for all five categories of gas-fired generation are provided in Appendix A.

Figure 4: Natural Gas Fuel Usage in California by Generation Category



Source: QFER CEC-1304 Power Plant Data Reporting.

Performance Comparison of 2010 to 2011

California saw a significant reduction in overall output from its natural gas generator fleet in 2011 due primarily to the abundant availability of hydroelectric generation. Total energy from natural gas-fired generation fell roughly 21,000 GWh hours to 96,000 GWh.

To better describe how the combined cycle, aging, and peaker power plants operated compared to one year ago, a subset of generation data was used to estimate the number of hours power plants operated each year. The data measured megawatt hours (MWh) generated in a single hour for each power plant.[13] Readings included nonoperational hours, recorded as zero MWh as well as ramping periods (partial startup and shutdown output applied over the whole hour). A threshold value of 10 MWh was used as proxy indicator that a power plant was on-line in a given hour. **Table 6** and **Table 7** compare the total on-line hours for gas-fired generation in 2010 and 2011.

As all power plants in the subset of data had a capacity of 50 MW or greater, the use of a 10 MWh threshold adequately captured significant ramping while avoiding inconsequential data readings. All values less than 10 MWh, including zero and negative values (negative readings result from station load measurements during standby periods), were counted together as *Remaining Available Hours*. Lastly, the data did not provide enough information to determine individual generating unit load levels. For example, there are no data available that measure the hourly energy output for the split between the combustion turbine and the steam turbine in a combined cycle unit. Accordingly, drawing conclusions about load levels based on these data is not possible. A tabular comparison of the operational results for the two years is shown in **Table 6**.

Table 6: Operational Comparison 2010 vs. 2011

	Combined Cycle		Aging		Peakers	
	2010	2011	2010	2011	2010	2011
Capacity Sampled (MW)	11,343	11,343	12,232	12,232	3,673	3,871
Units Sampled	24	24	38	38	67	71
Total Hours Sampled	194,880	209,088	322,848	331,056	565,752	604,056
On-line (Output Above 10 MWh)	113,274	92,201	28,611	48,124	22,286	27,449
Remaining Available Hours	81,606	116,887	294,237	282,932	543,466	576,607
On-line as a Percentage of Total Hours	58%	44%	9%	15%	4%	5%
Remaining Available Hours	42%	56%	91%	85%	96%	95%

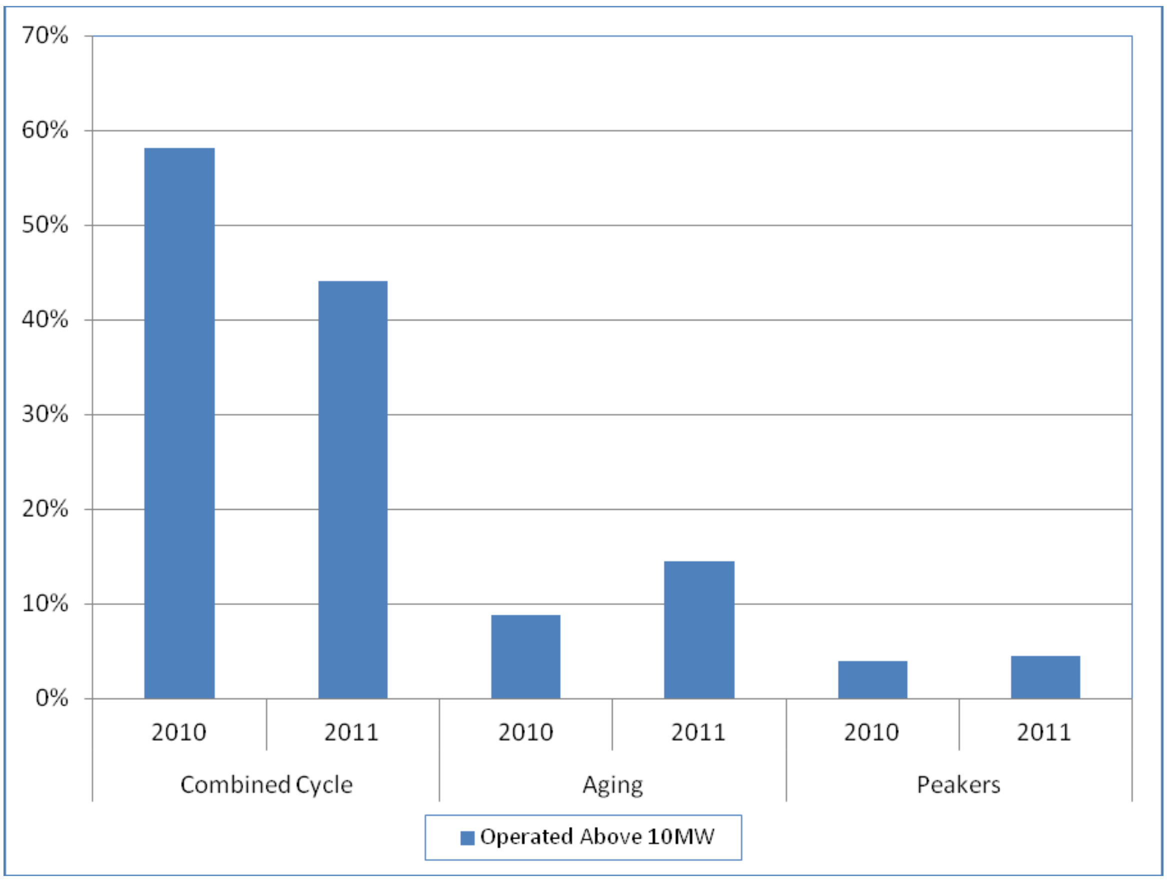
Source: California Independent System Operator (California ISO) aggregated confidential hourly data obtained under subpoena.

Note: While each unit should have 8,760 observations for each year, the sample data did not contain a complete record for each year. The year 2011 was short by 2 days while 2010 was missing 11 days of observations. Due to both additions and retirements, record counts at the category level may be slightly off.

13 For example, a 500 MW power plant operating at 50 percent output will produce 250 MW of energy in an hour.

Different sample sizes for the 2010 and 2011 hourly data make absolute comparisons of on-line hours difficult to assess. Both data sets had missing dates that spanned across all categories of generation. However, comparisons can be made using percentages to determine the ratio of on-line hours for each category. **Figure 5** summarizes the percentages presented in **Table 6** by charting the ratio of on-line hours for combined cycle, aging, and peakers for 2010 and 2011. With overall gas-fired generation down in 2011, **Table 6** reveals that combined cycle units operated 44 percent of the available hours, a decline of 14 percent from 2010. However, aging plants operated more hours in 2011 despite producing less total energy compared to 2010.

Figure 5: On-Line Hours as a Percentage of Total Hours



Source: Aggregated from California ISO data.

The hourly sample data was further categorized based on whether the observed generation occurred on peak or off-peak hours. Peak hours are defined as those hours from hour-ending 0700 (HE07) through hour-ending 2200 (HE22), Monday through Saturday, not including North American Electric Reliability Corporation (NERC) holidays. The remaining hours are considered off-peak.[14] For simplicity, the NERC holidays were not removed from the peak hour sample due to complexity and because the differences do not affect the general conclusions. Observations of high loads during a NERC holiday would be counter to standard expectations. **Table 7** builds upon the information in **Table 6** and summarizes the sample data for peak and off-peak operational periods.

Table 7: Usage During Peak and Off-Peak Hours

	Combined Cycle		Aging		Peakers	
	2010	**2011**	**2010**	**2011**	**2010**	**2011**
Capacity Sampled (MW)	11,343	11,343	12,232	12,232	3,673	3,871
Units Sampled	24	24	38	38	67	71
Total Hours Sampled	194,880	209,088	322,848	331,056	565,752	604,056
Peak Hours HE07 – HE22 Monday through Saturday						
On-Line Hours	69,489	59,964	18,914	29,769	19,066	22,527
Remaining Available Hours	42,831	59,460	167,134	159,319	309,966	322,481
Off-Peak Hours HE01 – HE06 & HE23 – HE24 Monday through Saturday + All Hours Sunday						
On-Line Hours	43,785	32,237	9,697	18,355	3,220	4,922
Remaining Available Hours	38,775	57,427	127,103	123,613	236,500	254,126
On-line Profiles						
Peak	36%	29%	6%	9%	3%	4%
Off-Peak	22%	15%	3%	6%	1%	1%

Source: Aggregated from California ISO data.

California's gas-fired combined cycle plants not only produced less energy in 2011, but also operated fewer hours during both peak and off-peak periods. **Figure 6** shows the proportion of hours each power plant category operated during peak and off-peak periods. The sample data for combined cycle generation reveals a consistent 7 percent decline in operation in each period. Peakers operated slightly more often during peak times in 2011 and about the same percentage of time during off-peak periods. Aging plants increased their operation by 50 percent during peak hours and doubled their operating hours during off-peak times compared to 2010. Unfortunately, the hourly data does not provide information on the contractual arrangements behind the power generation observed, such as the provision of voltage control, frequency response, and other ancillary services. The 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.

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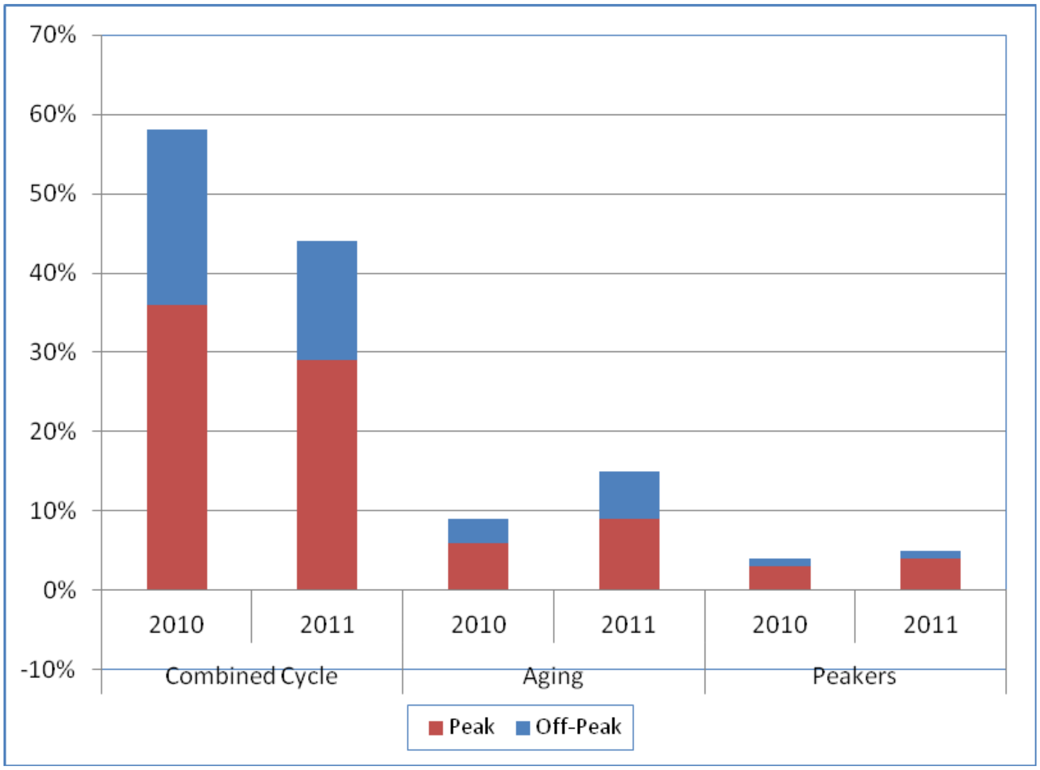
14 California ISO: Real-Time Daily Market Watch Metric Catalog, http://www.caiso.com/2426/2426c05e14b00.pdf.

Without this additional information, the significance of the year-over-year changes remains unclear.

Figure 6: On-Line Hours Based on Time of Day



Source: Aggregated from California ISO data.

Conclusion

California has experienced a significant improvement in the thermal efficiency of its in-state natural gas power plants over the last 11 years. From 2001 to 2011, thermal efficiency has improved 21 percent.

- This improvement in efficiency is due to the increased reliance upon combined cycle power plants, which are currently operating at a 37 percent capacity factor.
- By contrast, aging power plants now operate at a 4 percent capacity factor, compared to 43 percent capacity factor in 2001.
- Additionally, aging units saw a slight increase in hours during 2011, resulting in an overall increased heat rate for gas-fired generation compared to 2010.
- The higher heat rate lessened some of the potential reductions of GHG emissions that resulted from a 16 percent decline in gas-fired generation.
- The thermal efficiency of the state's portfolio of natural gas power plants continues to offer significant reductions in GHG emissions compared to 11 years ago.
- The complexities of determining the heat rates of cogeneration facilities prevent direct comparison to other gas-fired generation. This is due to the fundamental differences that cogeneration presents because it has multiple forms of energy output.

Acronyms

Acronym	Definition
Btu	British thermal unit
Btu/kWh	British thermal unit per kilowatt hour
California ISO	California Independent System Operator
CHP	Combined heat and power
GHG	Greenhouse gas
GWh	Gigawatt hour
HE	Hour ending
kWh	Kilowatt hour
MMBtu	Million British thermal units
MW	Megawatt
MWh	Megawatt hour
NERC	North American Reliability Council
OTC	Once-through-cooling

APPENDIX A:
Annual Data Tables

Table A-1: Percentage Share of Gas-Fired Generation in California 2001–2011

	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Aging	61.8%	38.7%	26.9%	23.0%	16.8%	14.9%	12.8%	11.8%	9.0%	5.4%	5.9%
Cogeneration	32.5%	44.2%	41.9%	37.7%	37.9%	32.0%	28.9%	27.1%	27.4%	28.7%	32.9%
Combined-Cycle	3.4%	15.3%	28.6%	36.3%	42.2%	50.9%	56.0%	58.9%	61.5%	63.8%	57.8%
Other	0.7%	0.8%	1.5%	1.8%	1.9%	1.2%	1.2%	0.9%	0.7%	0.9%	1.7%
Peaker	1.6%	1.0%	1.1%	1.2%	1.2%	1.0%	1.1%	1.3%	1.4%	1.2%	1.7%
Grand Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Source: QFER CEC-1304 Power Plant Data Reporting.

Table A-2: Total Capacity of Gas-Fired Generation in California 2001–2011

Capacity (MW)											
	2001	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**
Aging	19,272	18,948	18,622	18,174	17,539	17,649	17,649	17,114	17,114	16,698	15,694
Cogeneration	6,398	6,478	6,526	6,392	6,396	6,394	6,375	6,337	6,324	6,299	6,070
Combined Cycle	1,845	3,785	6,631	7,795	10,295	12,131	12,998	14,674	16,413	17,163	17,163
Other	1,380	1,360	1,635	1,592	1,336	1,345	1,123	888	884	1,034	1,121
Peaker	2,222	3,174	3,836	4,028	3,814	3,865	4,475	5,013	5,602	5,708	5,801
Grand Total	31,117	33,745	37,250	37,981	39,378	41,383	42,620	44,026	46,337	46,902	45,850

Source: QFER CEC-1304 Power Plant Data Reporting.

Table A-3: Capacity Factors for Gas-Fired Generation in California 2001–2011

	2001	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**
Aging	42.7%	21.7%	15.6%	15.2%	10.6%	10.6%	10.3%	10.2%	7.5%	4.2%	4.1%
Cogeneration	67.8%	72.3%	69.5%	70.9%	65.9%	62.5%	64.1%	63.3%	61.1%	59.6%	59.3%
Combined Cycle	24.6%	42.7%	46.8%	56.0%	45.5%	52.4%	60.8%	59.5%	53.0%	48.6%	36.8%
Other	7.3%	5.8%	9.8%	13.8%	16.8%	11.2%	15.3%	16.8%	10.8%	11.2%	15.7%
Peaker	9.3%	3.4%	3.2%	3.7%	3.4%	3.3%	3.4%	3.8%	3.5%	2.7%	3.3%
Grand Total	42.8%	31.4%	29.1%	31.7%	28.2%	30.2%	33.2%	33.7%	30.5%	27.9%	23.8%

Source: QFER CEC-1304 Power Plant Data Reporting.

APPENDIX B: 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 methodologies that are used to determine metrics to evaluate CHP systems: total system efficiency, and effective electrical efficiency.

The calculation for total system efficiency (Eff_{total}) 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 component (Q) from the 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.[15]

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 are debated, negotiated, and agreed upon numbers. They are not universally accepted and making those assumptions is outside the scope of this paper.

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