California’s Combined-Cycle Costs in the Age of the Duck Curve

Regional Considerations of Renewable Penetration Impacts on Combined-Cycle, Non-Fuel O&M Costs

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How Are California’s Combined Cycles Surviving?

To keep the lights on, California is increasingly reliant on renewables and gas-fired combined cycles (CCs). We thought it would be interesting to look more closely at the effects these new operational realities are having on costs, especially the effect of the “duck curve” on California’s CCs. To do so, we decided to explore the following questions:

1. Are California’s CCs running more and more often to support the duck curve year round?
2. Are California’s CCs non-fuel operating and maintenance (NFOM) costs increasing due to more hours of generating, more starts, and more ramping?
3. How do NFOM cost trends for CCs in California compare to trends elsewhere in the United States, where renewable penetration levels are lower? (For this question, we used the Southeast as a basis of comparison)

Here’s what we found:

1. **Output flat to declining:** Surprisingly, we also found there was no increase in capacity factors of California’s CCs
   - In fact, capacity factors have been flat since 2012, declining year-over-year from 2015 to 2016
   - Plants are cycling more to support the duck curve year round

2. **California’s CC costs have skyrocketed:** Our analysis confirmed that NFOM costs have increased markedly over the past 10 years
   - NFOM per megawatt hour (MWh) **more than doubled** from 2006 to 2016
   - A majority of the increase occurred from 2006 to 2013
   - NFOM per MWh has remained relatively steady since 2013

3. **Costs for comparable plants have decreased:** A peer plant’s NFOM costs decreased between 2006 and 2016
   - The average capacity more than doubled in peer groups between 2006 and 2016

We found that the changing dynamics in California have led to higher costs and lower total net generation for California’s CCs.
The California Duck Curve Is Real and Bigger than Expected

CAISO performed a detailed analysis to understand changing grid conditions. Its analysis showed that the net load, which is the load served by the electric system minus the load served by variable generation, will drop mid-day and quickly ramp to a late-day peak. This analysis resulted in the iconic “duck curve” chart.

- Increasing penetration of renewable resources (primarily utility-scale solar) produces the iconic duck curve, indicating that as variable generation grows so too will the trough of load served by conventional supply in mid-day. The actual data confirms the prediction and shows it to have been conservative.
- The CC plants examined in this analysis support the steep ramps, which occur when the system operator must rapidly bring on or shut down generation resources to meet increasing or decreasing electricity demand.
- The difference between minimum and maximum net load has become more severe each year, and forecasts suggest this will continue.

As the build-out of renewables is outpacing some of the most aggressive expectations in some power markets, particularly California, planners and grid operators are expressing more urgent concerns about resource availability to support ramping needs to maintain grid stability.

- A monotonic rise in renewables in California: Renewable growth in California is not rising and falling in fits and starts, it is growing steadily.
- The build-out of renewables is expected to continue as states continue to solicit renewables.
- Grid reliability will become an issue when intermittent resources become a sufficiently large portion of the generation assets, according to NERC.
Evidence of Cycling Becoming More Severe in California

The steady increase in renewable penetration in California may be driving the increase in NFOM costs for California’s CCs

- The duck curve in California is supported by CC plants, which are flexible enough to ramp swiftly and provide enough capacity to fulfill the generation demand (i.e., combustion turbines are typically smaller and don’t provide enough generation)
- The afternoon/evening ramp has become steeper, increasing the wear on plants
  - The graph on the bottom left shows that CC plants in California are generating less, but they are required to increase their generation more quickly than in years past
- The graph on the bottom right demonstrates a starkly different situation in the southeastern United States, where penetration of renewables is lower
  - CCs in the Southeast are running more in recent years, suggesting these units are being used more for baseload operations
  - Unlike California, in the Southeast, CCs are not needed to increase generation dramatically in the late afternoon hours

Note: Two NERC sub-regions (SOU and VACAR) were used as a proxy for the southeastern United States.
Sources: EPA CEMS data, ScottMadden analysis
Initial Findings: Capacity Factor Is Flat to Declining

Question #1: Are California’s CCs running more and more often to support the duck curve year round?

What we expected to find:

- An increase in California’s plants capacity factors:
  - There was an increase in gas generation across the board as gas prices dropped
  - Severe drought prior to 2016–2017 could have reduced the generation from hydro plants (explored in depth later)

What we found:

- There was no increase in California’s plants capacity factors (in fact, they have been flat since 2012, declining year-over-year from 2015 to 2016, perhaps due to an uptick in hydro)
- CC plants may be starting more, but they are running less overall
- California’s CC plants are generating less, but ramping faster

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California’s CC Capacity Factor Trend (2006–2016)*

*Outliers removed to ensure data integrity.

Capacity factor for California’s CCs has been flat since 2012, and it has declined year-over-year from 2015–2016.
Initial Findings: California’s CC Costs Have Increased

Question #2: Are California’s CC NFOM costs increasing due to more hours of generating, more starts, and more ramping?

What we expected to find:
- An increase in California’s CC NFOM costs:
  - An increase in the number of starts and stops could cause more wear and tear on the units
  - A less sustained generation may reduce the total generation

What we found:
- There was an increase in NFOM/MWh in California's plants despite the flat average capacity factor
- Since the typical pattern is for NFOM per MWh to remain constant with relatively flat average capacity factor, this would strongly suggest that cycling is increasing these costs

Results

NFOM costs for California’s CCs have increased in the past decade.

*Outliers removed to ensure data integrity.

Costs are all real, depicted in 2016 dollars.

Sources: FERC Form 1, SNL Financial, ScottMadden analysis
Initial Findings: Comparable CC Costs Have Decreased

Question #3: How do NFOM cost trends for CCs in California compare to trends elsewhere in the United States, where renewable penetration levels are lower?

What we expected to find:

- In the Southeast, we expected to find an increase in CC plants capacity factors:
  - There is an increasing reliance on gas-fired generation capacity in the region due to decreasing gas prices and retirement of coal-fired capacity
- In the Southeast, we found a decrease in CC NFOM per MWh:
  - An increase in capacity factors means a larger denominator for per unit costs to be divided into (NFOM/MWh)
  - Plants may increasingly be running as baseload, which allows operators to plan maintenance and outages more effectively

What we found:

- We found exactly what we expected to find:
  - Comparable CCs in the southeastern United States experienced markedly higher output over the past 10 years.
  - Costs at comparable CC plants in a region with less renewable penetration have declined significantly over the past 10 years

Sources: FERC Form 1, SNL Financial, ScottMadden analysis

Costs for comparable plants in the southeastern United States have declined.

Costs are all real, depicted in 2016 dollars.

*Outliers removed to ensure data integrity.
What About the Impact of Hydropower in California?

Cheap hydropower from the northwestern United States may be displacing power from CCs in California—when it is available

- Hydro output could explain some capacity factor fluctuations, particularly as hydro generation in the northwestern United States has a tendency to displace other incumbent generation capacity, particularly in northern California
- California’s CC plants and hydro capacity factors appear to be almost perfectly negatively correlated (see bottom left)
  - A drought in California from 2001–2015 led to a decline in hydro capacity factor and an increase in CC plants capacity factor
  - Those trends reversed in 2016, reflecting the wet winter and the corresponding availability of additional hydro power in 2016
- Hydro penetration as a percentage of total generation appears to be a function of availability compared to the consistent increase in other renewables, which have enjoyed generous policy support in California (see bottom right)

Sources: FERC Form 1, SNL Financial, ScottMadden analysis
Potential Takeaways and Considerations

These dynamics may be coming to a jurisdiction near you

- Renewable capacity has been steadily increasing in the United States, and regions which have seen, or are expected to see, a significant increase in solar and wind capacity may want to examine the potential cost and operational impacts on CCs
  - Future duck curve sightings may well occur sooner than expected in states with growing utility-scale solar and wind, such as Arizona, Georgia, Nevada, North Carolina, and Texas
  - Understanding the root cause and comprehensive impact of the duck curve is essential before developing strategies to address operational impacts on the rest of the generation fleet
- This could lead to significant changes in the cost profiles of CC fleets in other regions, and operators may need to fundamentally rethink how their fleets are operated
- CC operators everywhere need to be anticipating these dynamics and seeking opportunities to:
  - Implement strong asset management programs
  - Manage their generation fleets more efficiently

Other potential implications:

- **Grid modernization** initiatives and **demand side management** options may provide part of the solution in California and other regions with higher renewables if they enable or provide rapid capacity in response to the ramping needs in the late afternoon and evening
- Transmission and increasing regionalization (e.g., expansion of the **Energy Imbalance Market** in the West) could have huge implications for operating and balancing additional variable generation on the system while maintaining reliability
  - Additional regionalization efforts are being considered and evaluated throughout the United States
  - Importing and exporting power with neighboring systems may provide the ability to reduce curtailments when excess renewable generation is available and to reduce ramping when additional capacity is needed
  - System operators may need to rethink how inter-regional and intra-regional power flows and tie lines are managed
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Methodology

Peer Groups

- We developed a peer group of comparable CC plants in California and other regions for examination
  - California peer group:
    - We began with a list of all gas-fired CCs located in California, and we applied the following filters:
      - Regulated plants only (only rate-base, cost-of-service plants)
      - Capacity greater than 100 MWs
      - Removed co-generators
    - A peer group was identified using different NERC region/sub-region data
  - Comparable peer group from the southeastern United States:
    - We explored several potential options for peer groups, with the goal of identifying 15–20 comparable plants operating in markets which provided a contrast with California
    - Using the same filters used for the California plants, we identified a group of peer plants located in two contiguous NERC sub-regions in the southeastern United States—SOU and VACAR (Southeastern and Virginia and Carolinas)—to provide a basis of comparison

Data and Calculations

- Using data from publicly available filings (FERC and EIA), we assembled NFOM cost data, net generation, and capacity factor for each plant from 2006 to 2016
- NFOM cost was calculated on a per-MWh basis for each plant
- Finally, in order to provide a more precise understanding of renewable penetration trends, we collected data on renewable generation as a percentage of total regional generation for the two peer groups

*Outliers Removed

- Outlying NFOM values were removed from the sample
  - Values larger than the sample mean plus the standard deviation were removed

Appendix

Regional Comparison

<table>
<thead>
<tr>
<th></th>
<th>California’s CC Plants</th>
<th>SOU + VACAR CC Plants</th>
</tr>
</thead>
<tbody>
<tr>
<td># of Plants</td>
<td>11</td>
<td>18</td>
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<tr>
<td>Avg. MW</td>
<td>451</td>
<td>922</td>
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<tr>
<td>Avg. Year First Unit in Service</td>
<td>2003</td>
<td>2004</td>
</tr>
<tr>
<td>Avg. Year Latest Capacity Added</td>
<td>2007</td>
<td>2006</td>
</tr>
</tbody>
</table>

Note: After outliers removed
Additional Findings: Merchant CC Costs Follow Trend

Question #3 (Cont’d): Do cost trends for CCs hold for merchant plants?

What we expected to find:

- In California, we expected to find an increase in merchant CC plants NFOM costs
  - An increase in the number of starts and stops could cause more wear and tear on the units
- In the Southeast, we expected to find a decrease in merchant CC NFOM costs
  - An increase in capacity factors means a larger denominator for per unit costs to be divided into (NFOM/MWh)
  - Plants may increasingly be running as baseload, which allows operators to plan maintenance and outages more effectively

What we found:

- We found exactly what we expected to find:
  - Merchant CCs in California experienced a rise in NFOM costs since 2006
  - Costs at merchant CC plants in the Southeast have declined significantly over the past 10 years

Costs for merchant plants follow the same trend as regulated plants.

Sources: FERC Form 1, SNL Financial, ScottMadden analysis

Costs are all real, depicted in 2016 dollars.

*Outliers removed to ensure data integrity.
Appendix

Additional Findings: Regulated + Merchant CC Costs

Sources: FERC Form 1, SNL Financial, ScottMadden analysis

Costs are all real, depicted in 2016 dollars.

*Outliers removed to ensure data integrity.
# California Regulated CC Plant Details

<table>
<thead>
<tr>
<th>Plant</th>
<th>Year in Service</th>
<th>Year Latest Capacity Added</th>
<th>Nameplate Capacity (MW)</th>
<th>NERC Sub-Region</th>
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</thead>
<tbody>
<tr>
<td>Colusa CC (Maxwell)</td>
<td>2010</td>
<td>2010</td>
<td>668</td>
<td>CA</td>
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<tr>
<td>Cosumnes</td>
<td>2006</td>
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<td>Desert Star Energy Center (El Dorado)</td>
<td>2000</td>
<td>2000</td>
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<tr>
<td>Gateway Generating Station</td>
<td>2009</td>
<td>2009</td>
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<td>Magnolia Power Project</td>
<td>1984</td>
<td>2005</td>
<td>305</td>
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<td>Mountainview Power CC</td>
<td>2005</td>
<td>2006</td>
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<td>Palomar CC</td>
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<td>Redding CC</td>
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<td>Roseville Energy Park</td>
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<td>2007</td>
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<td>Scattergood Repowering CC</td>
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<td>Von Raefeld</td>
<td>2005</td>
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### Appendix

#### Peer CC Plant Details – SOU and VACAR NERC Sub-Regions

<table>
<thead>
<tr>
<th>Plant</th>
<th>Year in Service</th>
<th>Year Latest Capacity Added</th>
<th>Nameplate Capacity (MW)</th>
<th>NERC Sub-Region</th>
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<tr>
<td>Barry CC</td>
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<td>SOU</td>
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<tr>
<td>McIntosh Combined Cycle</td>
<td>2005</td>
<td>2005</td>
<td>1,302</td>
<td>SOU</td>
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<td>Plant Ratcliffe (Kemper County CC)</td>
<td>2014</td>
<td>2014</td>
<td>824</td>
<td>SOU</td>
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<tr>
<td>Victor J. Daniel Jr. CC</td>
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<td>2001</td>
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<td>Bear Garden</td>
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<td>VACAR</td>
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<tr>
<td>Bellemeade Power Station</td>
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<tr>
<td>Brunswick County Power Station</td>
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<tr>
<td>Buck CC</td>
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<tr>
<td>Chesterfield CC</td>
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<td>Dan River CC</td>
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<tr>
<td>Jasper County</td>
<td>2004</td>
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<td>L V Sutton CC</td>
<td>2013</td>
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<tr>
<td>Warren County Power Station</td>
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<td>1,472</td>
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