Commitment Cost Enhancements Phase 3 Opportunity Cost Methodology

Technical Appendix

April 22, 2016

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1. Introduction

This technical appendix documents the proposed design and methodology for determining opportunity cost (OC) adders for use-limited resources. The ISO is proposing to include OC adders to the commitment cost bid caps and/or the resource's Default Energy Bid (DEB) to enable a more optimal and efficient use of these resources given the limitations that are not considered by the current market optimization.

Commitment Cost Enhancements Phase 3[1] initiative developed a revised definition of use-limited to align use-limited status with resources needing an opportunity cost in commitment costs to be optimally committed due to restrictions which extend beyond the ISO's market optimization.

The ISO issued a draft final proposal on February 17, 2016, which was approved by the Board of Governors at the March 25th Board of Governor's Meeting. This technical appendix is intended to provide transparency to the proposed methodology and calculation of opportunity costs. These formulas were initially provided in the straw and revised straw proposals, but were removed from the draft final as the ISO committed to providing a technical appendix with more detail.

The technical appendix is organized as follows:

- Section 2 provides a high level description of what constitutes an opportunity cost, the proposed methodology, and how it will facilitate a more optimal and efficient use of use-limited resources.
- Section 3 describes the model inputs and formulation of inputs, along with a comparison of estimated locational marginal prices (LMPs) based on the proposed methodology to actual locational marginal prices (LMPs).
- Section 4 provides the formulation of the resource-specific opportunity cost model.
- Section 5 provides examples of how the opportunity cost model will determine opportunity costs for sample resources with various combinations of limitations.
- Section 6 provides the various permutations on cost estimate formulas for non-gas fired resources with and without greenhouse gas compliance obligations.
- Section 7 provides more detailed information on the data sources necessary for the cost estimate calculations.

2. Overview of opportunity cost

Use-limited resources have start and run limitations due to environmental or other operational restrictions. These restrictions extend beyond a one-day period and therefore cannot be explicitly recognized in the ISO market commitment decision. For example, an environmental restriction may limit a resource's run time over a single month to only 200 hours. However, the ISO's day-ahead market only considers a single day.

The ISO's optimization does not currently take into account that dispatching a resource in the current day may restrict its ability to run later in the month. When a resource runs in lower-

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[1] See the Draft Final Proposal posted at:
http://www.caiso.com/informed/Pages/StakeholderProcesses/CommitmentCostEnhancementsPhase3.aspx

priced hours, it incurs an opportunity cost to the extent it is not available in higher priced hours. Including opportunity costs in commitment costs, however, can allow the ISO market to optimally commit these resources by considering the limitations that extend beyond a single day, such as over a month or a year.

Commitment Cost Enhancements Phase 3 proposed a methodology to determine resource-specific opportunity costs for limitations of use-limited resources. If the resource and limitations lend itself to be modeled, the opportunity cost will be determined by modelling the market commitment of these resources based on projected locational marginal prices. The ISO will update these opportunity costs monthly throughout the year to reflect each resource's actual commitment by the market. Sections 3 through 5 below go into more detail of the opportunity cost model. Resources and limitations that cannot be modeled utilizing the method below can receive a negotiated opportunity cost.

The end result enables use-limited resources to reflect the opportunity costs in daily commitment costs bids. This increases market efficiency by increasing consistent participation of use-limited resources and allowing the market to determine the most optimal commitment and use of use-limited resources.

3. Opportunity cost model inputs

This section discusses resource characteristics and market inputs used in the optimization model.

3.1 Resource characteristics and constraints

The ISO will use the following Master File characteristics in the resource-specific opportunity cost model. The most recent values will be used in the model. The labels provided in parentheses will be the notation of that variable used throughout the technical appendix.

- Minimum operating level (Pmin)
- Maximum operating level (Pmax)
- Minimum on time (MOT)
- Minimum down time (MDT)

The ISO will rely on limitations identified on the use-limit plan data template (ULPDT) to determine the resource's use-limitation(s). The limitation(s) will be in terms of maximum starts (MaxSTRT), run-hours (MaxHRS), and/or output (MaxMWH). When the opportunity cost is updated as a resource is part way through the limitation horizon, the limitation used in the model will be based on the remaining available limitation.

3.2 Estimated costs

The model will use estimated variable energy, minimum load, and start-up costs of the resource. The commitment cost estimates will be based on the proxy cost formulas as described in the

Market Instruments Business Practice Manual[2] with adjustments necessary to forecast the costs over the modeled time horizon. The variable energy cost calculation will be a megawatt weighted cost based on the Default Energy Bid formulation, or equivalent, as described in Attachment D of the Market Instruments BPM.

The following formulas are for gas-fired resources. The permutations of the formulas for non-gas fired resources can be found in Section 6.

Variable energy cost

The model will use an estimated variable energy cost (VEC_m) for each month in the model for the entire output range of the resource. The monthly VEC will be based on the resource-specific megawatt weighted average heat rate, monthly forward natural gas prices, and the most recent natural gas transportation costs, greenhouse gas costs, and O&M adder. The monthly VEC will be determined as follows:

(1) $VEC_m = \sum(SegMW_i * (HR_i / 1{,}000 * (NatGasF_{m,l} + GasT_{m-1,k} + GHGas_{m-1} * EmRate_k) + O\&M)) / \sum(SegMW_i)$

Where:

$SegMW_i$ is the megawatts in heat rate segment i

HR_i is the heat rate for segment i

$NatGasF_{m,l}$ is the Natural Gas futures price for month m for fuel region l

$GasT_{m-1,k}$ is the most recent gas transportation cost of resource k

$GHGas_{m-1}$ is the most recent greenhouse gas price, if resource is subject to greenhouse
gas costs

$EmRate_k$ is the resource specific greenhouse gas emissions rate per MMBtu of natural gas
     for resource k

O&M   is the operating and maintenance adder for the resource

Commitment costs

For commitment costs, the ISO will calculate monthly proxy start-up and minimum load costs using the proxy cost formulations, adjusted for monthly forward natural gas prices, as follows:

(2) $SUC_m = (SUfuel*(NatGasF_{m,l} + GasT_{m-1,k})) + (AUX*EPI) + (SUFuel*GHGas_{m-1}*EmRate_k) + SU\_MMA + SU\_GMC$[3]

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[2] See Attachment G.2 for proxy cost formulas at https://bpmcm.caiso.com/Pages/BPMDetails.aspx?BPM=Market Instruments

[3] SU_GMC is determined by PMIN*Start up time in minutes / 60 mins per hour* (GMC adder/2)

Where:

SUC_m is the estimated monthly start-up cost for the resource

SUfuel   is the most recent start-up fuel value in Master File

$NatGasF_{m,l}$ is the Natural Gas futures price for month m for fuel region l

$GasT_{m-1,k}$ is the most recent gas transportation cost of resource k

AUX   is the most recent Auxiliary Energy value in Master File

EPI   is $NatGasF_{m,l,k}$ *10

$GHGas_{m-1}$ is the most recent greenhouse gas price, if resource is subject to greenhouse
gas costs

$EmRate_k$ is the resource specific greenhouse gas emissions rate per MMBtu of natural gas
for resource k

SU_MMA   is the most recent Major Maintenance Adder for starts

SU_GMC   is the GMC adder for starts[4]

(3) MLC_m = (PminHR * Pmin * ($NatGasF_{m,l}$+$GasT_{m-1,k}$)) / 1000 + ($GHGas_{m-1}$* $EmRate_k$ * PminHR)
/ 1000 + (O&M*Pmin) + ML_MMA + ML_GMC

Where:

MLC_m is the estimated monthly minimum load cost for the resource

PminHR   is the most recent heat rate at minimum operating point of the resource in Master
File

$NatGasF_{m,l}$ is the Natural Gas futures price for month m for fuel region l

$GasT_{m-1,k}$ is the most recent gas transportation cost of resource k

$GHGas_{m-1}$ is the most recent greenhouse gas price, if resource is subject to greenhouse
gas costs

$EmRate_k$ is the resource specific greenhouse gas emissions rate per MMBtu of natural gas
for resource k

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[4]SU_GMC is determined by $Pmin * (STARTUP\_RAMP\_TIME/60min) * \frac{GMC}{2}$

O&M   is the operating and maintenance adder for the resource

ML_MMA is the most recent Major Maintenance Adder for minimum operating point

ML_GMC is the GMC adder for minimum operating point[5]

3.3 Estimated LMPs

The opportunity cost model will determine the optimal commitment of the resource using the above described resource characteristics, constraints, and estimated costs. The model will also use estimated fifteen minute locational marginal prices (LMPs). The ISO will estimate real-time prices by:

1. Calculating an implied marginal heat rate at each use-limited resource's pricing node (Pnode) based on fifteen minute real-time energy prices from the same time period the previous year.
2. Calculating a power price conversion factor based on the ratio of an implied heat rate of future power prices and an implied heat rate of historical power prices
3. Scaling the implied heat rate from (1) by the power price conversion factor from (2).
4. Estimating the fifteen minute real-time energy prices by applying the natural gas future prices, gas transportation costs, and greenhouse gas costs to the scaled implied heat rates from (3).

Each step is described in more detail below.

Each interval's and location's LMP is assumed to reflect the heat rate of a marginal unit, and that heat rate can be inferred from the prices of gas and emissions allowances at that time and place. This procedure will allow the implied heat rate to inherently capture real-time price volatility, which will then be used to forecast future prices.

A set of resource specific 15 minute implied heat rates, $ImpHR_{i,t-1}$, will be determined as follows:

$$(4)\ \mathrm{Im}\,pHR_{i,t-1} = \frac{LMP_{i,t-1}}{GPI_{t-1,k} + (GHGas_{t-1} * EmRate)}$$

Where:

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[5] ML_GMC is determined by Pmin*GMC adder

$LMP_{i,t-1}$ is the fifteen minute real time energy price at pnode *i* from the previous year's period, *t-1*.

$GHGas_{t-1}$ is the daily greenhouse gas allowance price from the previous year's period, *t-1*.

EmRate   is the greenhouse gas content of natural gas, which is *.0531148mtCO2e/MMBtu*[6]

$GPI_{t-1,k}$ is the daily gas price index of resource k, of the previous year's period, t-1

The power price conversion factor will adjust the historical implied heat rate for any anticipated changes in wholesale energy prices that are not reflected in natural gas future prices.

The power price conversion factor will be generated as follows:

$$(5) PPConv_{h,m} = \frac{ImpHRF_{h,m,tou}}{ImpHRH_{h,m-12,tou}}$$

Where:

$ImpHRF_{h,m,tou}$ is the implied heat rate based on the future power price at hub *h* for the analysis month *m* and time of use *tou* (peak or off peak), calculated as:

$$(5.1) ImpHRF_{h,m,tou} = \frac{PPF_{h,m,tou}}{NatGasF_{m,l} + (GHGas_{m-1} * EmRate)}$$

Where:

$PPF_{h,m,tou}$ is the future power price at hub *h* of pnode *i,* for the analysis month *m* and interval time of use *tou..*

$NatGasF_{m,l}$ is the Natural Gas futures price for month *m* for fuel region *l*

$GHGas_{m-1}$ is the average greenhouse gas allowance price from the previous month, *m-1*

EmRate   is the greenhouse gas emissions rate per MMBtu of natural gas, which is *.0531148mtCO2e/MMBtu*

And where:

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[6] Per EPA

$ImpHRH_{h,m-12,tou}$ is the implied heat rate based on average monthly power price at hub h from the same month the previous year, $m-12$, and time of use (peak or off peak), tou, calculated as:

$$(5.2) ImpHRH_{h,m-12,tou} = \frac{PP_{h,m-12,tou}}{NatGas_{m-12,l} + (GHGas_{m-12} * EmRate)}$$

Where:

$PP_{h,m-12,tou}$ is the monthly average power price at hub h of pnode i from the previous time period $m-12$, and interval time of use tou.

$NatGas_{m-12,l,k}$ is the monthly average of daily natural gas price from the region l of resource k of the previous year's period, $m-12$

$GHGas_{m-12}$ is the monthly average greenhouse gas allowance price from the previous year's period, $m-12$.

$EmRate$ is the greenhouse gas content of natural gas, which is $.0531148 mtCO2e/MMBtu$

The estimated resource-specific 15-minute real-time energy prices will be generated as follows:

$$(6)\ LMPi, t = ImpHR_{i,t-1} * PPConv_{h,m,tou} * \left(NatGasF_{l,m} + GasT_{m-1,k} + (GHGas_{m-1} * EmRate)\right)$$

Where:

$LMP_{i,t}$ is the forecasted real time price at pnode i for interval t

$ImpHR_{i,t-1}$ is the calculated implied heat rate at pnode i from the previous year's period, $t-1$

$NatGasF_{m,l}$ is the Natural Gas futures price for month m for fuel region l

$GasT_{m-1,k}$ is the average gas transportation cost for region l of resource k from the previous month

$GHGas_{m-1}$ is the average greenhouse gas allowance price from the previous month.

$EmRate$ is the greenhouse gas content of natural gas, which is $.0531148 mtCO2e/MMBtu$

$PPConv_{h,m,tou}$ is the conversion factor based on future power prices at a given hub h for the analysis interval m and time of use, tou

The end result is a set of resource-specific estimated 15-minute real-time energy prices. These estimated prices will be used in the opportunity cost model, along with the estimated resource costs and characteristics to estimate the dispatch of the resource over the modeled time period.

3.3.2 Comparison of estimated and actual market LMPs

The methodology for estimated LMPs in the straw proposal for Commitment Cost Enhancements Phase 3 did not include the conversion factor based on future power prices; that proposed enhancement was first introduced in the revised straw proposal. The follow two figures are intended to illustrate the impact the conversion factor has on the estimated LMPs relative to 1) the original estimated LMP methodology and 2) actual market LMPs for two resources. The estimated and actual LMPs are fifteen minute real-time LMPs from January 1, 2015 through December 31, 2015.

The fifteen minute LMPs for both resources were first estimated without the conversion factor, labeled "Estimated LMP" and sorted in descending order. The LMPs were then estimated with the conversion factor, labeled "Estimated LMP with conversion factor" and sorted in descending order. Lastly the actual market fifteen minute LMPs for the same time period, for the specific resource, were sorted in descending order. All three price series for the same resource over the same time horizon are plotted on the following charts in descending order. The more accurate the distribution of the estimated LMPs is to the actual LMP distribution, the more accurate the resulting opportunity costs.

For ease of comparison, the top portion of the distribution curves, representing 250 hours (or 1,000 fifteen minute intervals) are shown. Given the resources are limited in starts, run-hours, and/or output, the opportunity costs will occur in the upper portion of the distribution curve. As shown in both charts, the estimated LMPs with the conversion factor tends to more closely follow the actual LMPs, most notably when the distribution curve initially starts to flatten out. The estimated LMPs without the conversion factor tend to be consistently lower than the actual LMPs.

Figure 1   Distribution of estimated and actual fifteen minute LMPs for Resource A
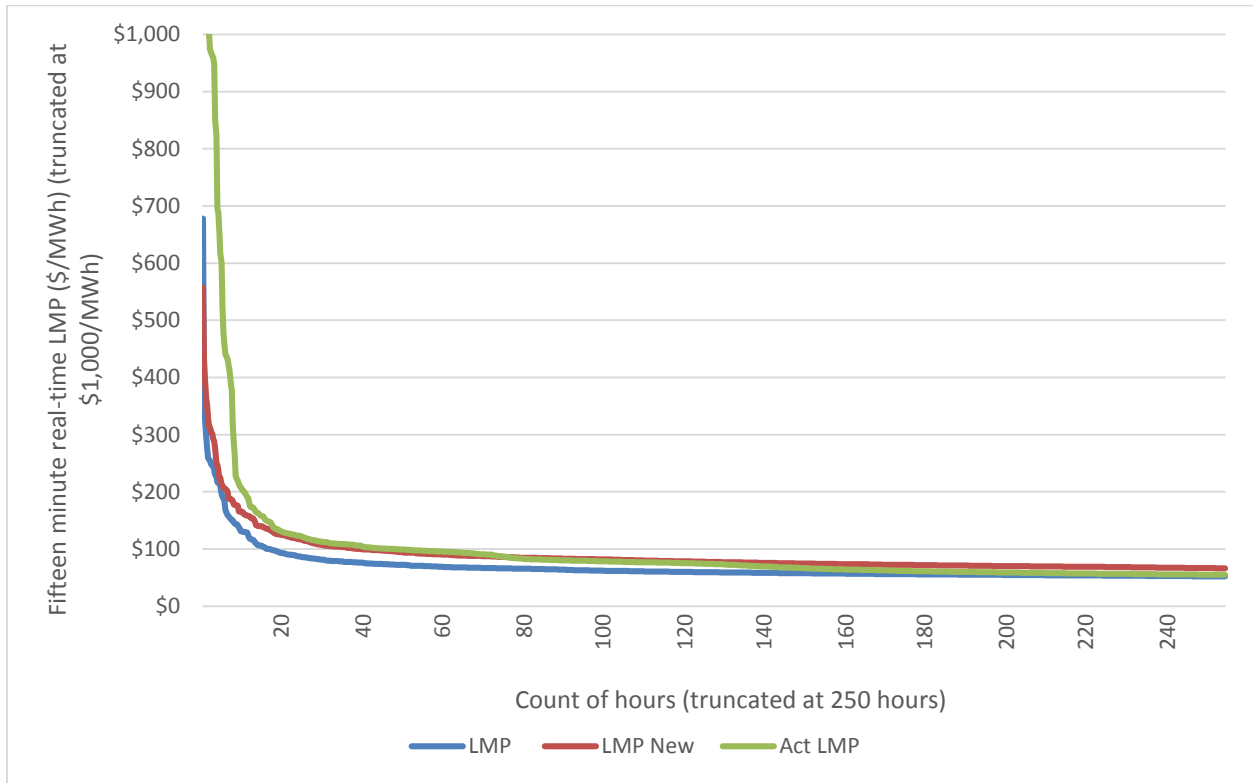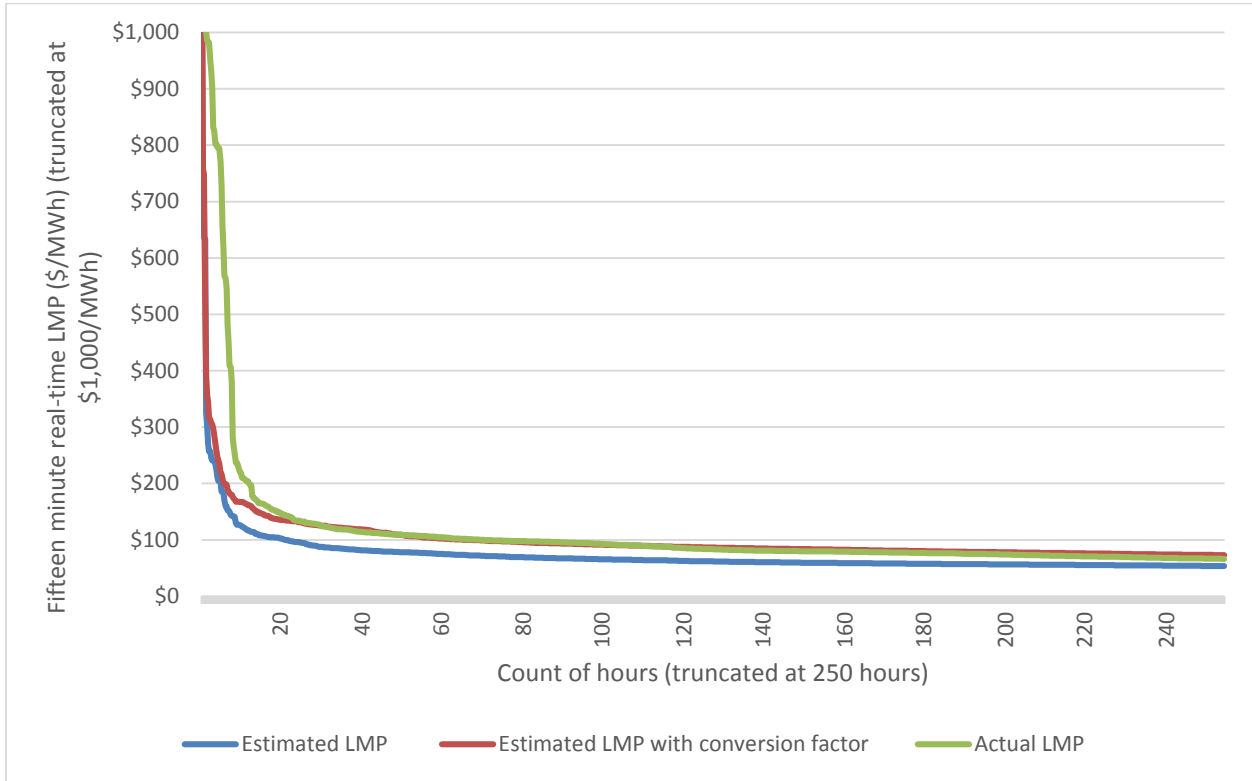(top 1,000 intervals)

Figure 2   Distribution of estimated and actual fifteen minute LMPs for Resource B

(top 1,000 intervals)

4. Opportunity cost model formulation

The opportunity cost methodology estimates the foregone profits of the last start, run-hour, and/or MWh assuming the resource is committed when most valued. The objective function of the opportunity cost model will be to maximize total profits given the estimated LMPs, estimated costs, resource characteristics, and constraints. Below is the mathematical formulation of the profit maximizing objective function based on fifteen minute real-time intervals:

$$(7)\ Max\ \pi = \sum_{i=1}^{n}\left[LMP_i * \frac{MWh_i}{4} - VEC * \frac{(MWh_i - Pmin)}{4} - \frac{MLC}{4} - \frac{SUC}{TotalInt}\right]$$

Where:

LMP_i is the estimated 15 minute LMP, for interval i, at the resource's node

MWh_i is the optimal commitment and dispatch of the resource during interval i[7]

VEC is the estimated variable energy cost as determine by equation 1, 1.1, or 1.2

MLC is the estimated minimum load cost of the resource as determined by equation 3, 3.1, or 3.2

SUC is the estimated start-up cost of the resource as determined by equation 2, 2.1, or 2.2

$TotalInt$ is the total consecutive 15 minute intervals the resource is running during the dispatch horizon (prior to being shut down by the model)

Subject to:

(7.1) MWhi >= Pmin if committed

(7.2) MWhi <= Pmax if committed

(7.3) Count(i, where MWhi is between Pmin and Pmax during consecutive intervals)/4 >= MOT

(7.4) Count(i, where MWhi is zero during consecutive intervals)/4 >= MDT

(7.5) SUM(Startups) <= .90*(MaxSTRT- ActSTRT) over the limitation horizon, if resource has a limitation on starts and where ActSTRT is actual incurred starts during the limitation horizon.

(7.6) Count(*i,* where *i* is between Pmin and Pmax and i is within the limitation horizon)/4 <=.90*(MaxHRS – ActHRS), if resource has a limitation on run-hours and where ActHRS is actual incurred run-hours during the limitation horizon.

(7.7) SUM(MWh$_i$/4) <= .90*(MaxMWH – ActMWH), if resource has a limitation on output and where ActMWH is actual output during the limitation horizon.

Note: The last three constraints represent the limitations for which an opportunity cost needs to be calculated. A resource may have one, two, or all three limitation types. A resource may have more than one limitation type with different applicability horizons (annual and monthly start limitations).

The solution to the objective function is the estimated profits of the resource over the modeled horizon. This estimated profits will then be used to determine the opportunity cost for each limitation type, starts, run-hours, and output by reducing the limitation by one and re-running the model. The difference in the two objective functions is the opportunity cost for that limitation type.

The next section provides illustrative examples on how the model will be used to determine the

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[7] The model uses a single variable energy cost estimate, therefore the MWh value will either be 0, minimum operating point, or maximum operating point.

initial opportunity cost, and how the opportunity cost will be updated as the year progresses.

5. Examples of opportunity cost model

The following examples are intended to better illustrate how the model will be utilized to determine opportunity costs for various limitations, and combinations thereof. It also serves to provide clarity as to how the limitations will be set and run in each model.

Examples 1 through 4 below illustrate how the model will determine the opportunity cost for annual and monthly limitations, as well as updating the opportunity costs as the year progresses.

Note, that if a resource only has an annual limitation examples 1 and 2 will still apply without the monthly limitation in the model. If a resource only has a monthly limitation, examples 3 and 4 will still apply without the annual limitation.

Examples 5 and 6 illustrate how the model will determine the opportunity cost for nested limitations. Nested limitations refer to limitations of the same type, e.g., start, but over different time horizons, e.g., annual and monthly.

Example 7 illustrates how the model will determine the opportunity cost for a rolling 12 month limitation.

5.1   Example 1: Calculating the opportunity cost for annual limitation

Assume the example resource has 300 starts per year and 400 run hours per month.

Run the model as described in Section 4, optimizing January through December. Set the annual maximum starts (MaxSTRT) to <= 270 (270 = 90% of 300 starts) and the maximum run hours (MaxHRS) for each month to <= 400 hours.

The resulting annual estimated profits is defined as "Base run annual profits".

Reduce the annual maximum starts (MaxSTRT) to <= 269 (269 = 90% of 300 starts, minus one start), and keep the maximum run hours (MaxHRS) for each month at <= 400 hours. Re-run the model.

The resulting annual estimated profits is defined as "Model run 2 annual profits".

The opportunity cost adder due to the annual limitation on starts is:

Base run annual profits – Model run 2 annual profits

The opportunity cost is valid for January through December, or until next model run updates this value. It will increase the start-up cost bid cap by the opportunity cost adder.

5.2   Example 2: Updating the opportunity cost for annual limitation from Example 1

Assume we are updating the opportunity cost on the last day of September for the remaining calendar year. The resource has actually started 250 times from January through September. Therefore there are 50 starts remaining for October through December.

Run the model as described in Section 4, optimizing October through December. Set the annual maximum starts (MaxSTRT) to <= 45 (45 = 90% of 50 remaining starts) and the maximum run hours for each month (MaxHRS) to <= 400 hours.

The resulting annual estimated profits is defined as "Base run annual profits updated".

Reduce the annual maximum starts (MaxSTRT) to <= 44 (44 = 90% of 50 starts, minus one start), and keep the maximum run hours (MaxHRS) for each month at <= 400 hours. Re-run the model.

The resulting annual estimated profits is defined as "Model run 2 annual profits updated".

The updated opportunity cost adder due to the annual limitation on starts is:

Base run annual profits updated – Model run 2 annual profits updated

The opportunity cost is valid for October through December, or until the next model run updates this value. The updated opportunity cost supersedes any previously calculated opportunity cost adders for the same limitation and valid for the same months.

5.3 Example 3: Calculating the opportunity cost for monthly limitation

Run the model as described in Section 4, optimizing January through December. Set the maximum monthly run-hours (MaxHRS) to <= 360 hours per month (360 = 90% of 400 run-hours) and the maximum starts (MaxSTRT) to <= 300 starts per year.

The resulting monthly estimated profits are defined as "Base run Jan profits", "Base run Feb profits", "base run mar profits", . . . , "base run Dec profits"

Reduce the monthly maximum run-hours (MaxHRS) to <= 359 for each month in the model (359 = 90% of 400 run-hours, minus one run-hour), and keep the maximum starts (MaxSTRT) at <= 300 starts per year. Re-run the model.

The resulting monthly estimated profits are defined as "Model run 2 Jan profits", "Model run 2 Feb profits", "Model run 2 Mar profits", . . . , "Model run 2 Dec profits"

The opportunity cost adder for each month due to the monthly limitation on run-hours are:

Jan: Base run Jan profits – Model run 2 Jan profits

Feb: Base run Feb profits – Model run 2 Feb profits

Mar: Base run Mar profits – Model run 2 Mar profits

. . .

Dec: Base run Dec profits – Model run 2 Dec profits

The opportunity cost valid for each month can differ and will be valid for the corresponding month until next model run updates the value. It will increase the minimum load cost bid cap by the opportunity cost adder.

5.4 Example 4: Updating the opportunity cost for monthly limitation in Example 3

Assume we are updating the opportunity cost on the last day of September for the remaining calendar year. Because the run-hour limitation is a monthly limitation, there is no adjustment needed based on the actual run-hours of the resource January through September.

The resource also has a start limitation of 300 starts per year; assume the resource has actually started 250 times from January through September. Therefore, there are 50 starts remaining for October through December.

Run the model as described in Section 4, optimizing September through December. Set the maximum monthly run-hours (MaxHRS) to <= 360 hours per month (360 = 90% of 400 run-hours) and the maximum starts (MaxSTRT) to <= 50 (50 = 300 starts – 250 actual starts January through September) for the remainder of the year.

The resulting monthly estimated profits are defined as "Base run Oct profits", "Base run Nov profits", and "Base run Dec profits"

Reduce the monthly maximum run-hours (MaxHRS) to <= 359 for each month in the model (359 = 90% of 400 run-hours, minus one run-hour), and keep the maximum starts (MaxSTRT) at <= 50 starts for the remainder of the year. Re-run the model.

The resulting monthly estimated profits are defined as "Model run 2 Oct profits", "Model run 2 Nov profits", "Model run 2 Dec profits"

The opportunity cost adder for each month due to the monthly limitation on run-hours are:

Oct: Base run Oct profits – Model run 2 Oct profits

Nov: Base run Nov profits – Model run 2 Nov profits

Dec: Base run Dec profits – Model run 2 Dec profits

The opportunity cost valid for each month can differ and will be valid for the corresponding month until next model run updates the value. These updated opportunity costs will supersede all previously calculated opportunity costs for the same month due to the same limitation type. The minimum load cost bid cap will be increased by the opportunity cost adder.

5.5 Example 5: Calculating the opportunity cost for the nested annual and monthly limitation

Limitations of the resource used in examples 5 and 6 are 300 starts per year, 30 starts per month, and 400 run-hours per month. The annual and monthly limitations on starts are considered to be nested.

A resource is considered to have a nested limitation when there are limits of the same type (start-up, run-hour, or output) with two different horizons (annual and monthly). The opportunity cost model will be able to determine the opportunity cost for the nested limitations simultaneously as follows.

Run the model as described in Section 4, optimizing January through December. Set the annual maximum starts (MaxSTRT$_a$) to <=270 (270 = 90% of 300 annual starts), the maximum starts (MaxSTRT$_m$) for each month to <= 27 (27 = 90% of 30 monthly starts), and the maximum run hours (MaxHRS) for each month to <= 400 hours.

The resulting annual estimated profits is defined as "Base run nested profits".

Reduce the annual maximum starts (MaxSTRT$_a$) to <= 269 (269 = 90% of 300, minus one start). Reduce the monthly maximum start (MaxSTRT$_m$) for January to <=26 (26 = 90% of 30 starts, minus one start). Keep the monthly maximum starts (MaxSTRT$_m$) for February through December at <=27 (27 = 90% of 30 starts). Keep the maximum monthly run-hour (MaxHRS) at <= 400 hours per month for each month in the model.

The resulting annual estimated profits is defined as "Model run 2 Jan nested profits".

Reduce the annual maximum starts (MaxSTRT$_a$) to <= 269 (269 = 90% of 300, minus one start). Reduce the monthly maximum start (MaxSTRT$_m$) for February to <=26 (26 = 90% of 30 starts, minus one start). Keep the monthly maximum starts (MaxSTRT$_m$) for January and March through December at <=27 (27 = 90% of 30 starts). Keep the maximum monthly run-hour (MaxHRS) at <= 400 hours per month for each month in the model.

The resulting annual estimated profits is defined as "Model run 2 Feb nested profits".

Continue to run the model reducing the maximum monthly starts (MaxSTRT$_m$) by one start, one month at a time, and resetting the previous month's maximum monthly starts to 27. Retain the maximum annual starts (MaxSTRT$_a$) at 269 starts per year. Note the estimated annual profits for each model run.

The opportunity cost adder for each month due to the nested start limitations are:

     Jan: Base run nested profits - Model run 2 Jan nested profits

     Feb: Base run nested profits - Model run 2 Feb nested profits

     Mar: Base run nested profits - Model run 2 Mar nested profits

. . .

     Dec: Base run nested profits - Model run 2 Dec nested profits

5.6   Example 6: Updating the opportunity cost for the nested annual and monthly limitation

Assume we are updating the opportunity cost on the last day of September for the remaining calendar year.

The resource also has a start limitation of 300 starts per year; assume the resource has actually started 250 times from January through September. Therefore, there are 50 annual starts remaining for October through December. There is no need to adjust the monthly start or run-hour limitation.

Run the model as described in Section 4, optimizing September through December. Set the annual maximum starts (MaxSTRT$_a$) to <=45 (45 = 90% of 50 remaining annual

starts), the maximum starts for each month (MaxSTRT$_m$) to <= 27 (27 = 90% of 30 monthly starts), and the maximum run hours (MaxHRS) for each month to <= 400 hours.

The resulting annual estimated profits is defined as "Base run nested profits".

Reduce the annual maximum starts (MaxSTRT$_a$) to <= 44 (44 = 90% of 50, minus one start). Reduce the monthly maximum start (MaxSTRT$_m$) for October to <=26 (26 = 90% of 30 starts, minus one start). Keep the monthly maximum starts (MaxSTRT$_m$) for November and December at <=27 (27 = 90% of 30 starts). Keep the maximum monthly run-hour (MaxHRS) at <= 400 hours per month for each month in the model.

The resulting annual estimated profits is defined as "Model run 2 Oct nested profits".

Reduce the annual maximum starts (MaxSTRT$_a$) to <= 44 (44 = 90% of 50, minus one start). Reduce the monthly maximum start (MaxSTRT$_m$) for November to <=26 (26 = 90% of 30 starts, minus one start). Keep the monthly maximum starts (MaxSTRT$_m$) for October and December at <=27 (27 = 90% of 30 starts). Keep the maximum monthly run-hour (MaxHRS) at <= 400 hours per month for each month in the model.

The resulting annual estimated profits is defined as "Model run 2 Nov nested profits".

Continue to run the model reducing the maximum monthly starts (MaxSTRT$_m$) by one start, one month at a time, and resetting the previous month's maximum monthly (MaxSTRT$_m$) starts to 27. Retain the maximum annual starts (MaxSTRT$_a$) at 44 starts per year. Note the estimated annual profits for each model run.

The opportunity cost adder for each month due to the nested start limitations are:

    Oct: Base run nested profits - Model run 2 Oct nested profits

    Nov: Base run nested profits - Model run 2 Nov nested profits

    Dec: Base run nested profits - Model run 2 Dec nested profits

The opportunity cost valid for each month can differ and will be valid for the corresponding month until next model run updates the value. These updated opportunity costs will supersede all previously calculated opportunity costs for the same month due to the same limitation type.

5.7 Example 7: Calculating the opportunity cost for a rolling annual limitation

Theoretically, the opportunity cost for the current twelve month period is affected by the opportunity cost of an indefinite number of rolling twelve month periods. To reasonably estimate the opportunity cost for the current twelve month period, the opportunity cost model will include at least two constraints. The constraint from M-11 to M and M to M+11 where M is the upcoming month.

In the following example, assume M is January 2016. It then follows that M-11 to M is February 2015 to January 2016 and M to M+11 is January 2016 to December 2016. Limitation of the resource used in this example is 300 starts over a rolling 12 month period. Assume the resource was started 280 times from February 2015 through December 2015, thus leaving 20 starts for January 2016.

Run the model as described in Section 4, optimizing January 2016 through December 2016. Set the maximum starts (MaxSTRT$_j$) for January to <=18 (18 = 90% of 20 remaining starts for January 2016) and set the maximum starts for January 2016 through December 2016 (MaxSTRT$_a$) to <= 270 starts (270 = 90% of 300 starts).

The resulting annual estimated profits is defined as "Base run rolling profits".

Reduce the maximum starts for January 2016 (MaxSTRT$_j$) to <= 17 (17 = 90% of 20 remaining starts for January 2016, minus one start) and the maximum starts for January 2016 through December 2016 (MaxSTRT$_a$) to <=269 (269 = 90% of 300 starts, minus one start). Rerun the model.

The resulting annual estimated profits is defined as "Model run 2 rolling profits".

The opportunity cost adder for the twelve month period of January 2016 through December 2016 due to the rolling start limitation is:

>   Base run rolling profits - Model run 2 rolling profits

This opportunity cost adder is valid from January 2016 through December 2016 until the next model run updates the opportunity cost adder due to the rolling limitation. The next model run for February 2016 through January 2017, would be conducted as described below.

In the next model run, M is February 2016. It then follows that M-11 to M is March 2015 to February 2016 and M to M+11 is February 2016 to January 2017. Limitation of the resource used in this example is 300 starts over a rolling 12 month period. Assume the resource was started 260 times from March 2015 through January 2016. Thus, leaving 40 starts for February 2016.

Run the model as described in Section 4, optimizing February 2016 through January 2017. Set the maximum starts for February (MaxSTRT$_f$) to <= 36 (36 = 90% of 40 remaining starts for February 2016) and set the maximum starts for February 2016 through January 2017 (MaxSTRT$_a$) to <= 270 starts (270 = 90% of 300 starts).

The resulting annual estimated profits is defined as "Base run rolling profits".

Reduce the maximum starts for February 2016 (MaxSTRT$_f$) to <= 35 (35 = 90% of 40 remaining starts for February 2016, minus one start) and the maximum starts for February 2016 through January 2017 (MaxSTRT$_a$) to <=269 (269 = 90% of 300 starts, minus one start). Rerun the model.

The resulting annual estimated profits is defined as "Model run 2 rolling profits".

The opportunity cost adder for the twelve month period of February 2016 through January 2017 due to the rolling start limitation is:

>   Base run rolling profits - Model run 2 rolling profits

This opportunity cost adder is valid from February 2016 through January 2017 until the next model run updates the opportunity cost adder due to the rolling limitation. This updated value supersedes the previously calculated opportunity cost adder that was valid for January 2016 through December 2016.

6. Permutations of cost estimate calculations for non-gas fired resources

As noted above, the cost estimate formulas in Section 3.2 were for gas-fired resources based on the proxy cost formulation of those costs for gas-fired resources. Attachment G of the Market

Instruments Business Practice Manual specifies how proxy costs are calculated for non-gas fired resources. To be consistent with those calculations, the cost estimates for non-gas fired resources used in the opportunity cost model will also be based on those calculations.

Below are the cost estimate formulas for variable energy cost, minimum load cost, and start-up costs, for non-gas fired resources without a Greenhouse gas compliance and for non-gas fired resources with a greenhouse gas complies. These formulas will be used to estimate the resource specific costs for the opportunity cost model.

6.1 Non-gas fired resource without a GHG compliance obligation

(1.1) $VEC_m = \sum(Seg\ MW_i * (AvgCostF_i + O\&M)) / \sum(Seg\ MW_i)$

Where:

Seg MW_i is the megawatts in cost curve segment i

O&M   is the Operations and Maintenance adder for the resource

$AvgCostF_i$ is the RDT submitted cost corresponding to the cost curve segment i

Start-up costs

(2.1) SUC_m = (RDTCostSU) + SU_MMA + SU_GMC

Where:

SUC_m is the estimated start-up cost for month m

RDTCostSU   is the most recent Masterfile start-up fuel or fuel equivalent cost

SU_MMA   is the most recent Major Maintenance Adder for starts

SU_GMC   is the GMC adder for starts[8]

Minimum load costs

(3.1) MLC_m = (RDTCostML + (O&M*Pmin) + ML_MMA + ML_GMC

Where:

MLC_m is the estimated monthly minimum load cost for the resource

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[8]SU_GMC is determined by $Pmin * (STARTUP\_RAMP\_TIME/60min\ ) * \frac{GMC}{2}$

RDTCostML   is the average fuel cost at minimum load per the most recent Masterfile costs[9]

O&M   is the operating and maintenance adder for the resource

ML_MMA   is the most recent Major Maintenance Adder for minimum operating point, if costs approved by the ISO

ML_GMC   is the GMC adder for minimum operating point[10]

6.2   Non-gas fired resource with a GHG compliance obligation[11]

For non-gas fired resources to have greenhouse gas compliance costs explicitly included in the proxy cost calculations below, they have to have submitted sufficient data for the ISO to conduct the calculations.

Variable energy cost

(1.2) $VEC_m = \sum(Seg\ MW_i * (AvgCostF_i + O\&M + (GHGas_{m-1} * EmRate_k))) / \sum(Seg\ MW_i)$

Where:

$Seg\ MW_i$ is the megawatts in cost curve segment i

$AvgCostF$ is the RDT submitted cost corresponding to the cost curve segment i

$GHGas_{m-1}$ is the most recent greenhouse gas price, if resource is subject to greenhouse gas costs

$EmRate_k$ is the resource specific greenhouse gas emissions rate per MMBtu of natural gas for resource k

O&M   is the operating and maintenance adder for the resource

Start-up costs

(2.2) $SUC_m = (RDTCostSU) + SU\_MMA + SU\_GMC + (SUFuel*GHGas_{m-1}*EmRate_k)$ [12]

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[9] Average fuel cost at minimum load for non-gas fired resources is the product of minimum load and the submitted Heat average cost in Masterfile corresponding to minimum load divided by 1,000.

[10] ML_GMC is determined by Pmin*GMC adder

[11] For GHG costs to be included for non-gas fired resources, the GHG compliance flag is Masterfile has to be set to 'Y' and all necessary data has been submitted by the SC via RDT.

[12] SU_GMC is determined by PMIN*Start up time in minutes / 60 mins per hour* (GMC adder/2)

Where:

SUC_m is the estimated monthly start-up cost for the resource

RDTCostSU   is the most recent Masterfile start-up fuel or fuel equivalent cost

SUfuel   is the most recent start-up fuel value in Master File

$GHGas_{m-1}$ is the most recent greenhouse gas price, if resource is subject to greenhouse
gas costs

$EmRate_k$ is the resource specific greenhouse gas emissions rate per MMBtu of natural gas
for resource k

SU_MMA   is the most recent Major Maintenance Adder for starts

SU_GMC   is the GMC adder for starts[13]

Minimum load costs

(3.2) MLC_m = (RDTCostML + (O&M*Pmin) + ML_MMA + ML_GMC + ($GHGas_{m-1}$* $EmRate_k$ * PminHR) /
1000

Where:

MLC_m is the estimated monthly minimum load cost for the resource

RDTCostML   is the average fuel cost at minimum load per the most recent Masterfile costs[14]

O&M   is the operating and maintenance adder for the resource

ML_MMA   is the most recent Major Maintenance Adder for minimum operating point, if costs
approved by the ISO

ML_GMC   is the GMC adder for minimum operating point[15]

$GHGas_{m-1}$ is the most recent greenhouse gas price, if resource is subject to greenhouse
gas costs

$EmRate_k$ is the resource specific greenhouse gas emissions rate per MMBtu of natural gas

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[13]SU_GMC is determined by $Pmin * (STARTUP\_RAMP\_TIME/60min) * \frac{GMC}{2}$

[14] Average fuel cost at minimum load for non-gas fired resources is the product of minimum load and the
submitted Heat average cost in Masterfile corresponding to minimum load divided by 1,000.

[15] ML_GMC is determined by Pmin*GMC adder

for resource k

PminHR is the most recent heat rate at minimum operating point of the resource in Master File

7. Input Data sources

Below is a table providing more information on the input data necessary for the ISO to calculate the cost estimates used in the opportunity cost model.

Input variable name	Description of variable	Data source	Comments/Examples	Equations using this variable[16]
Seg MW$_i$	Megawatts for each heat rate operating segment i for gas fired resources, or the cost curve segment for non-gas fired resources.	Masterfile		1, 1.1, and 1.2
HR$_i$	Heat rate for operating range segment i	Masterfile		1, 1.1, and 1.2,
NatGasF$_{m,l,}$	Natural gas futures price for month m and in fuel region l	Index Price	Resources in PGE2 fuel region will use the PG&E Citygate prices. Resources in SCE1, SCE2, SDGE1, and SDGE2 will use SoCal city gas prices. All others will use the minimum of PG&E and SoCal citygate prices. Based on using the average of several days' future prices.	1 ,2, 3, 5.1, and 6

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[16] The numbers in this column corresponds to the number labels next to each equation throughout the technical appendix.

GasT$_{m-1,k}$	Most recent month's gas transportation cost of the resource k	Index price	Resources will use the gas transportation costs based on territory rates as stated in Appendix C of the Market Instruments BPM.	1, 2, 3, and 6
GHGas$_{m-1}$	Average of most recent month's daily greenhouse gas allowance prices	Index price	Consistent with formulation in G.1.3 of Market Instruments BPM	1, 1.2, 2, 2.2, 3, 3.2, 5.1, and 6
EmRate$_k$	Greenhouse gas emissions rate of resource k	Masterfile	If resource k is not subject to greenhouse gas compliance obligations, then zero.	1, 1.2, 2, 2.2, 3, and 3.2
O&M[17]	Operations and Maintenance adder	Administrative Fee	See Market Instruments BPM for default O&M values.	1, 1.1, 1.2, 3, 3.1, and 3.2
EPI	Energy price index	Index price	To forecast all resource's EPI, EPI will be determined by NatGasP$_{m,r}$*10 for each month	2
SUFuel	Resource's Start-up fuel	Masterfile		1
AUX	Resource's auxiliary energy for start-ups	Masterfile		2 and 2.2
SU_MMA	Major maintenance adder for starts	Masterfile	As approved by the ISO, otherwise zero	2, 2.1, and 2.2
SU_GMC	Grid management charge applied to the start-up costs	Determined based on Masterfile values and Administrative fee	PMin*Startup ramp time/60*GMC adder/2 where GMC adder represents Market Services Charge and System Operations Charge.	2, 2.1, and 2.2

[17] See Exhibit 4.2 in Market Instruments BPM for default O&M adders by technology type at
https://bpmcm.caiso.com/Pages/BPMDetails.aspx?BPM=Market Instruments

ML_GMC	Grid management charge applied to the minimum load costs	Determined based on Masterfile values and Administrative fee	PMin*GMC adder where GMC adder represents Market Services Charge, System Operations Charge, and Bid Segment Fee.	3, 3.1, and 3.2
PMinHR	Heat rate at the minimum operating point	Masterfile		3 and 3.2
ML_MMA	Major maintenance adder for minimum load	Masterfile	As approved by the ISO, otherwise zero	3, 3.1, and 3.2
$LMP_{i,t-1}$	15 minute energy LMP at resource's pnode i, from the previous year	Market data	For example, when forecasting June 2016 15 minute energy LMPs, use June 2015 15 minute energy LMPs	4
$GHGas_{t-1}$	Previous year's daily greenhouse gas allowance prices	Index price	For example, when forecasting June 2016 energy LMPs, use the June 2015 daily greenhouse gas allowance price.	4
EmRate	Standard greenhouse gas emissions rate	As provided, and updated, by EPA	Currently .0531148mtCO2e/mmBTU. Same value for all resources as natural gas resources are assumed to be on the margin.	4, 5.1, 5.2, and 6
$GPI_{t-1,k}$	Daily gas price index for resource k from the previous year	Index price	For example, when forecasting June 2016, use the June 2015 daily gas price of indices. These values contain the gas transportation costs.	4

$PPF_{h,m,tou}$	Future power price of hub h, month m, and by time of use, tou		Based on same indices used to determine the wholesale EPI as stated in Appendix M of the Market Instruments BPM. NP15 prices for resources in PGE1 and PGE2 fuel regions. SP15 prices for all other regions.	5.1
$PP_{h,m-12,tou}$	Monthly average power price of hub h, month m, and time of use tou.		For example, when forecasting June 2016 prices, take the average daily power price of June 2015 from hub h by time of use. NP15 prices for resources in PGE1 and PGE2 fuel regions. SP15 prices for all other regions.	5.2
$NatGas_{m-12,l}$	Monthly average natural gas price from the previous year of region l, month m, and time of use tou.		For example, when forecasting June 2016 prices, take the average daily natural gas price of June 2015 from region l by time of use. Resources in PGE2 fuel region will use the PG&E Citygate prices. Resources in SCE1, SCE2, SDGE1, and SDGE2 will use SoCal city gas prices. All others will use the minimum of PG&E and SoCal citygate prices.	5.2
$GHGas_{m-12}$	Average of daily greenhouse gas allowance price from the same month of last year	Index Price	For example, when forecasting June 2016, take the average of daily greenhouse gas allowance prices from June 2015.	5.2
RDTCostSU	Most recent fuel equivalent start-up cost for non-gas fired resources.	Masterfile		2.1 and 2.2

RDTCostML	Most recent fuel equivalent minimum load cost for non-gas fired resources.	Masterfile		3.1 and 3.2
AvgCostF	Most recent fuel or fuel equivalent cost curve segment for non-gas fired resources.	Masterfile		1.1 and 1.2
MaxSTRT	Acceptable limitation on starts for the resource	Use-limitation plan data template		7.5
MaxHRS	Acceptable limitation on run-hours for the resource	Use-limitation plan data template		7.6
MaxMWH	Acceptable limitation on output for the resource	Use-limitation plan data template		7.7
ActSTRT	Actual starts incurred by the resource during the corresponding limitation horizon.	Settlement and market data	If an SC experiences a start not captured by settlement or market data, e.g., failed starts or testing, that start will be incorporated into the ActSTRT value if communicated to the ISO.	7.5
ActHRS	Actual run hours incurred by the resource during the corresponding limitation horizon.	Settlement and market data		7.6
ActMWH	Actual output of the resource during the corresponding limitation horizon.	Settlement and market data		7.7

8. Stakeholder comments

If you would like to submit written comments or questions, please send them to Initiativecomments@caiso.com by May 13, 2016.