Optimizing Combined Cycle Units in PJM's Wholesale Energy Markets Using a Hybrid Multiple Configuration Resource Model

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Outline

Combined Cycle Power Plant Characteristics and Trends

Combined Cycle Market Models

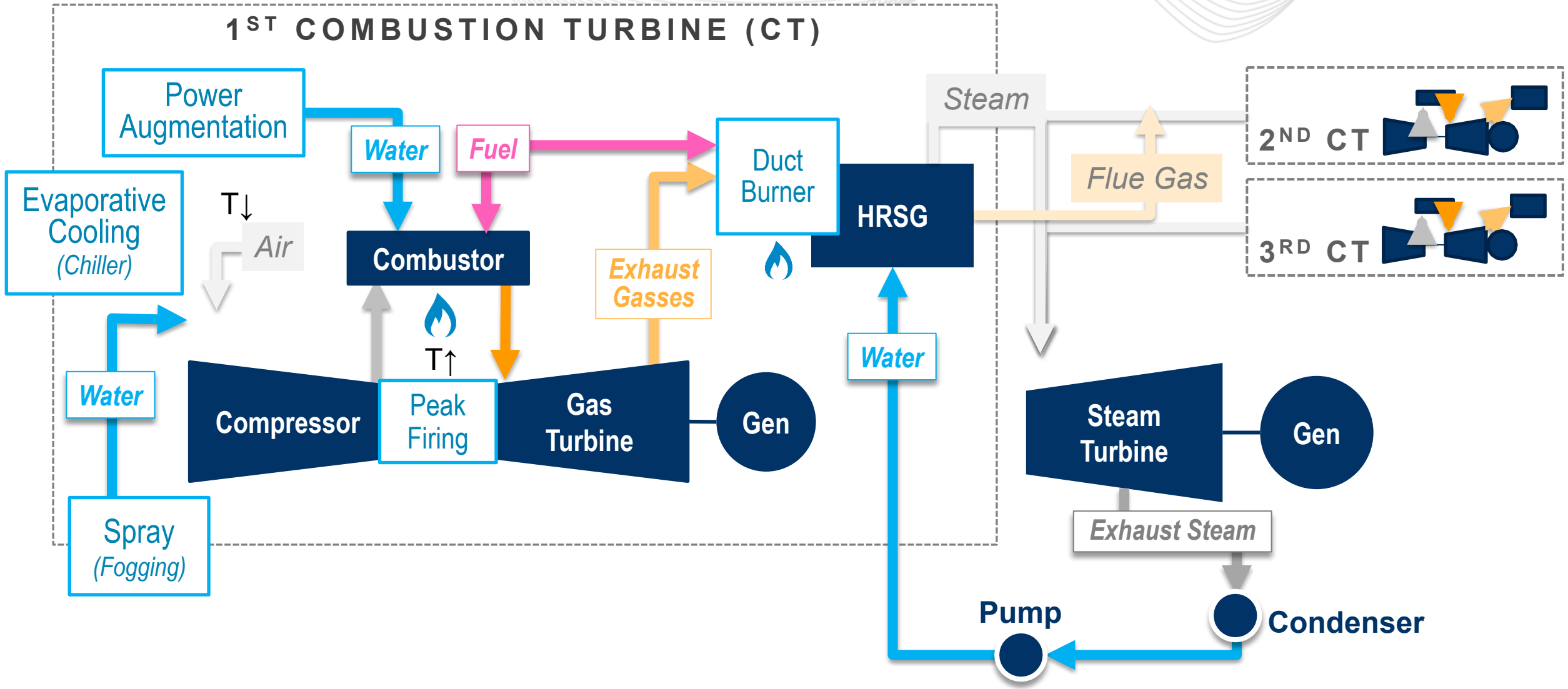
Simulations

- Methodology
- Results

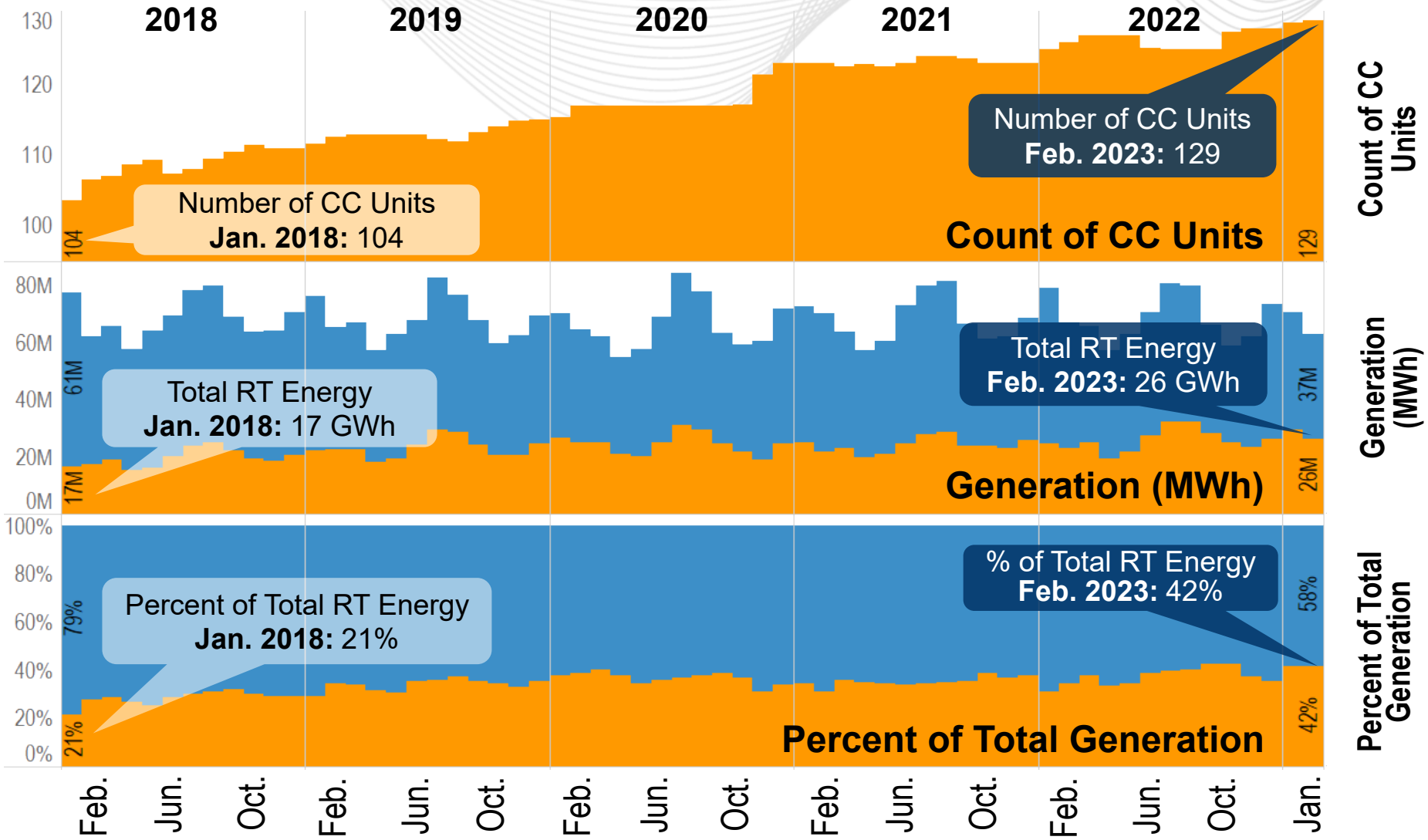
Observations & Next Steps

Questions

Combined Cycle Units Are Very Complex Machines



Combined Cycle Participation in PJM Energy Market: 2018–Feb. 2023



Traditional Combined Cycle Market Models Do Not Accurately Capture the Unit's Operating Characteristics

Traditional combined cycle market clearing models:

Entire resource modeled as a single unit	CT and fraction of ST modeled as separate units (e.g., CT + 1/3 ST)

Independent unit models have several disadvantages:

- Units cannot bid in with accurate costs.
- Reduced flexibility in DA commitment and dispatch
- Divergence between DA and RT physical models
- In the future, combined cycle units may be the primary marginal generators setting LMPs.

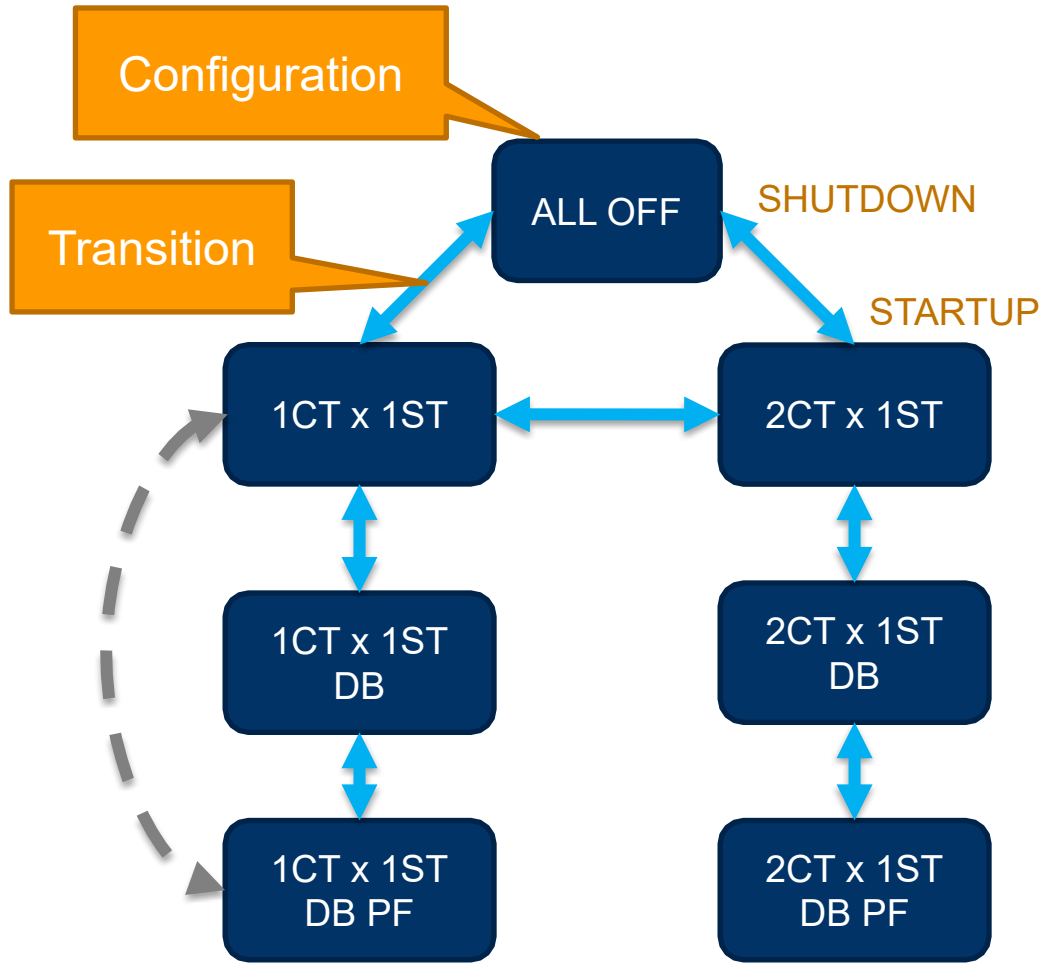
Recent improvements in mixed integer programming allows for greater ability to model a configuration-based combined cycle model.

What Is a Configuration-Based Combined Cycle Model?

Allows for the individual modeling of each “operating mode” of a combined cycle unit and its transitions

These “operating modes” define a state diagram/transition matrix.

- Configurations have operating limits (MW) and incremental costs ($/MWh).
- Transitions have costs ($, h).
- Switching is constrained (min. run).



Benefits of a Configuration-Based CC Model

Some benefits such as enhanced flexibility can be quantified via simulations.

Other benefits are hard to quantify.

- More accurate reserve scheduling
- Modeling that is better aligned with physical capabilities
  - Start-up
  - Convergence between DA and RT physical models

What Is a Hybrid Configuration/Component-Based Combined Cycle Model?

Improved configuration-based model: Added a component level to allow tracking and enforcing turbine minimum on/off time

Config->Turbine Mapping	Component (Turbine)		
CONFIGURATIONON	INDCT1ST1	INDCT2	INDDUCT
1CT1ST	1		
1CT1STDUCT	1		1
2CT1ST	1	1	
2CT1STDUCT	1	1	1
2CT1STDUCTPF	1	1	1

Benefits

- Captures all the benefits of the pure configuration-based model
- Able to track and enforce turbine minimum on/off time, which is an important operating constraint

Combined Cycle Model Implemented in PROBE

First implementations by other ISOs (CAISO, ERCOT, SPP) use explicit configuration models.	**Limited the maximum number of configurations for performance reasons**		
	SPP – 3 configurations	CAISO – 10 configurations	ERCOT – no limit

MISO proposed a hybrid configuration/component model called Enhanced Combined Cycle (ECC) model:

- Closer to a physical model
- More complicated and computationally intensive

See: https://www.ferc.gov/sites/default/files/2020-08/T4-1_Wang.pdf

PROBE's combined cycle model is the hybrid configuration/component type.

- **MCR** – Multiple Configuration Resource, more general term than ECC
- May be applied to other resources – pump storage, synchronous condensers, hybrid resources with storage
- No limit on the number of configurations (maximum 12 configurations seen in the test cases)

Simulation Challenges

Quantifying the benefits of a hybrid configuration/component-based CC model is challenging.

- Configuration and component level data and offers do not currently exist.
- Cannot compare price vs. cost-based offers
- Offer behavior will change as units become more familiar with the model.

Simulation Methodology Overview

- To estimate the impacts on bid production cost, a hybrid configuration/component-based CC model was implemented in the PROBE DA market clearing software.

Two cases were simulated, and the differences between the two were measured to estimate the impact to bid production cost:

BASE CASE:	CC CASE:
CC units on only their highest output configuration schedule that can transition to/from the off state	CC units on their full configuration-based schedules

- Virtual transactions were removed from the simulations to estimate the impacts to RT bid production cost.

Combined Cycle Model Configuration/Component Data

- Collaborated with PJM generator owners to collect accurate combined cycle configuration and component data

To date, have received data from over 40% of PJM's combined cycle units:	
46 units submitted data (39 unique plants).	Over 21,000 MW as measured by ecomax (out of approximately 50,000 MW)

Simulation Parameters:

- 364 days in 2021 (March 15 was excluded)
- 46 configuration-based CC units were simulated (39 unique plants).

Case Scenarios

1.	2.	3.
Base Case as described above	**CC Case** as described above	**Price Case** as offered, used for computational performance impact assessment

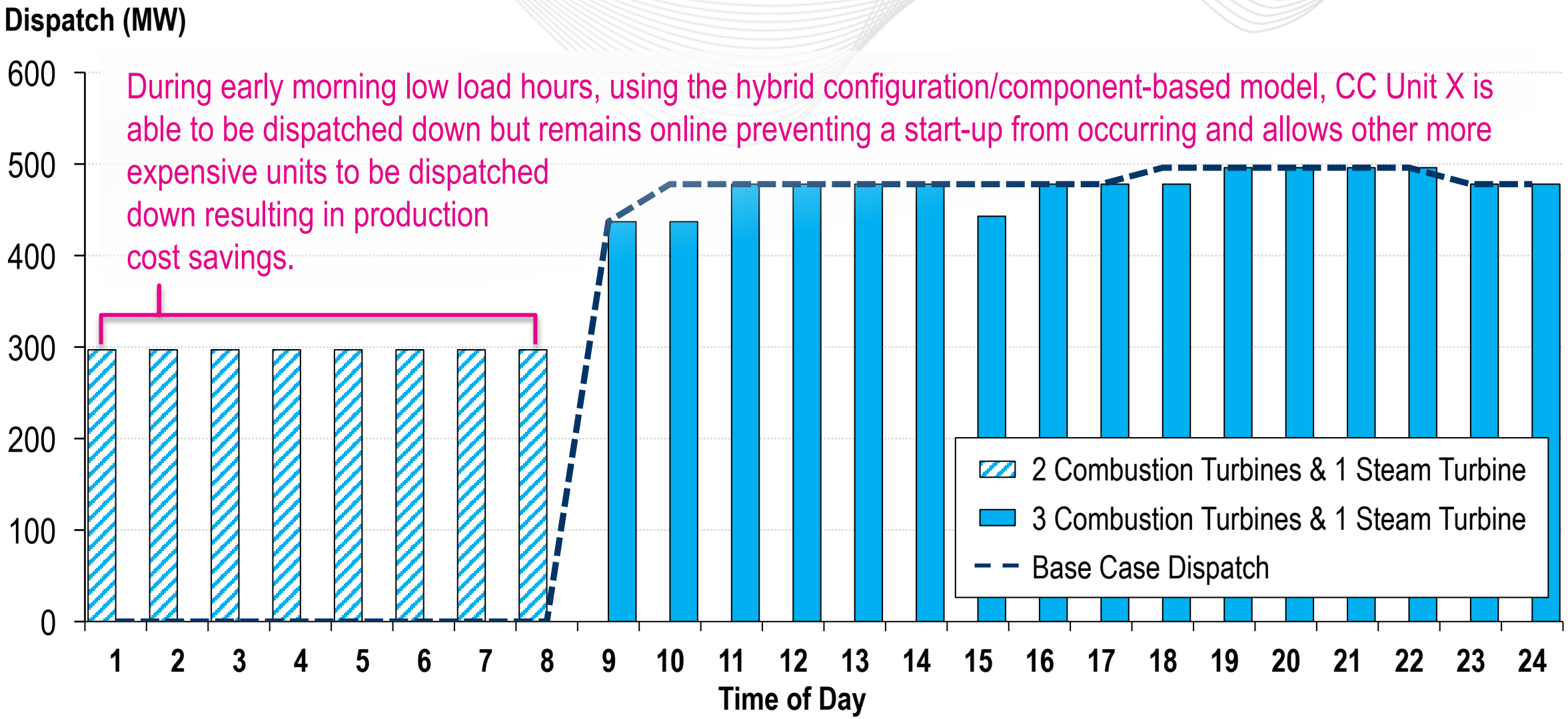
Simulation Limitations

Current analysis provides a preliminary estimate of the impacts of a hybrid configuration/component-based CC model on the PJM energy market.

The following limitations must be noted:

- No mitigation was enforced.
- No fast-start pricing (FSP) logic was included.
- No strategic bidding by the CC units on their configuration-based schedules was included (cost-based offers provided by PJM CC generator operators were used).
- Some PJM-specific parameters were not enforced (i.e., max. run hours).

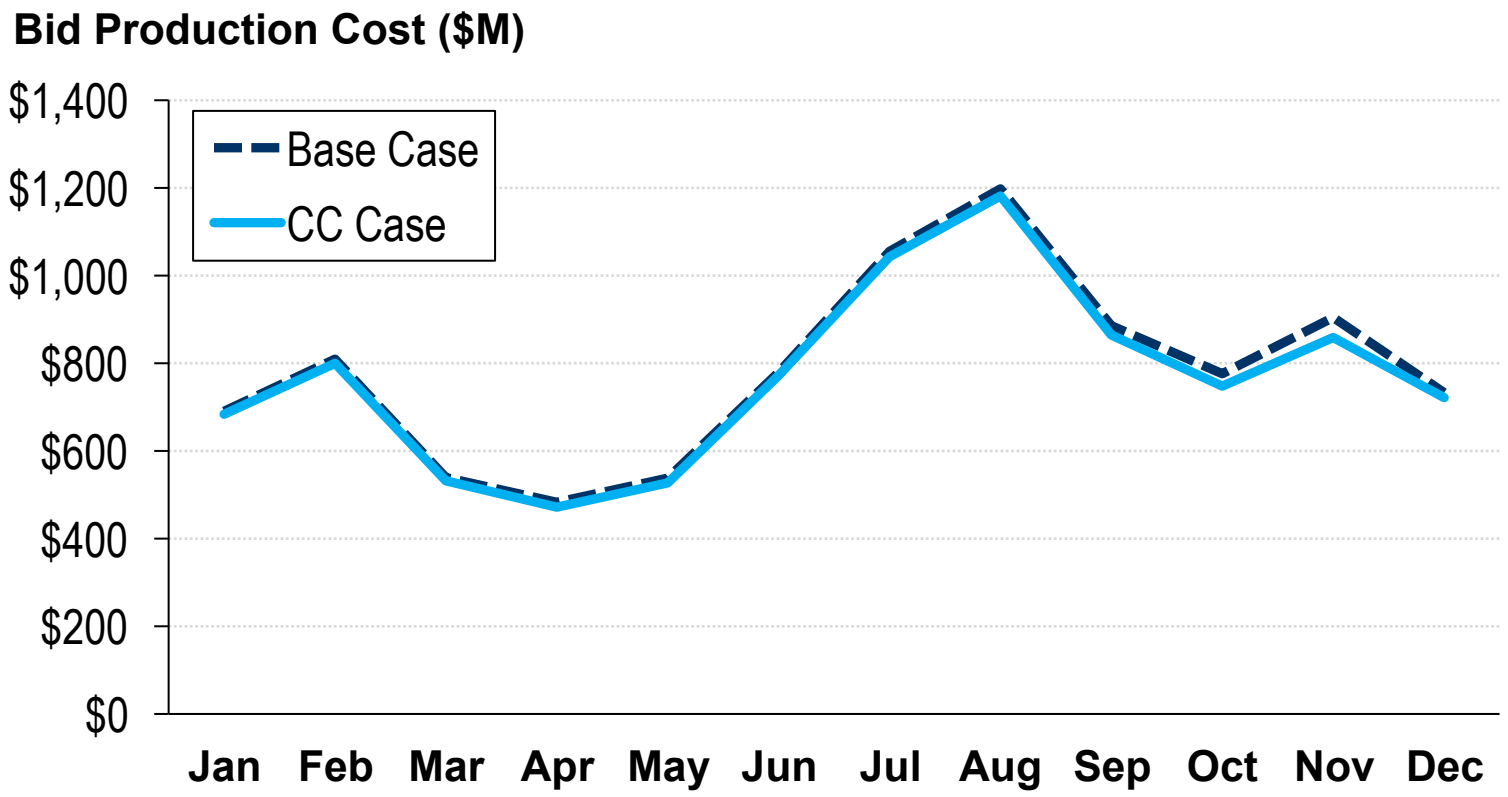
Example Single Unit Simulation Results – March 28, 2021



Simulation Results – Generator Bid Production Cost

Decrease in generator bid production cost:

Difference between the Base and the CC Case in 2021: $187 million (2.0%)

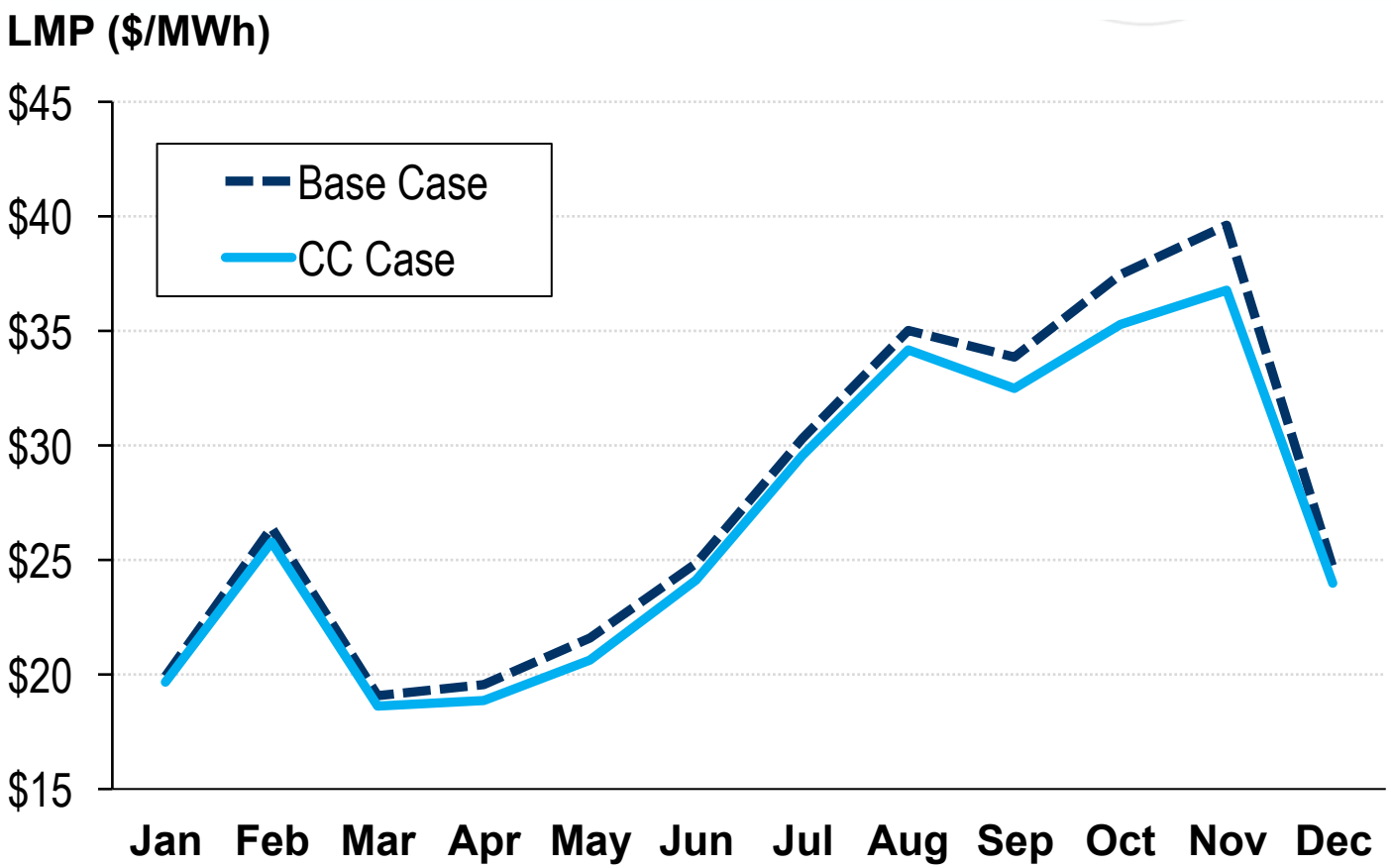


Month	Base Case – CC Case	% Change
Jan	$6,724,959	1.0%
Feb	$9,430,554	1.2%
Mar	$7,437,242	1.4%
Apr	$11,119,799	2.3%
May	$10,797,147	2.0%
Jun	$6,925,149	0.9%
Jul	$12,254,597	1.2%
Aug	$16,209,260	1.4%
Sep	$21,208,341	2.4%
Oct	$28,304,683	3.7%
Nov	$45,694,326	5.1%
Dec	$11,338,008	1.6%
2021	**$187,444,065**	**2.0%**

Simulation Results – Average Generator LMPs

Decrease in the average generator LMPs (note FSP was not implemented)

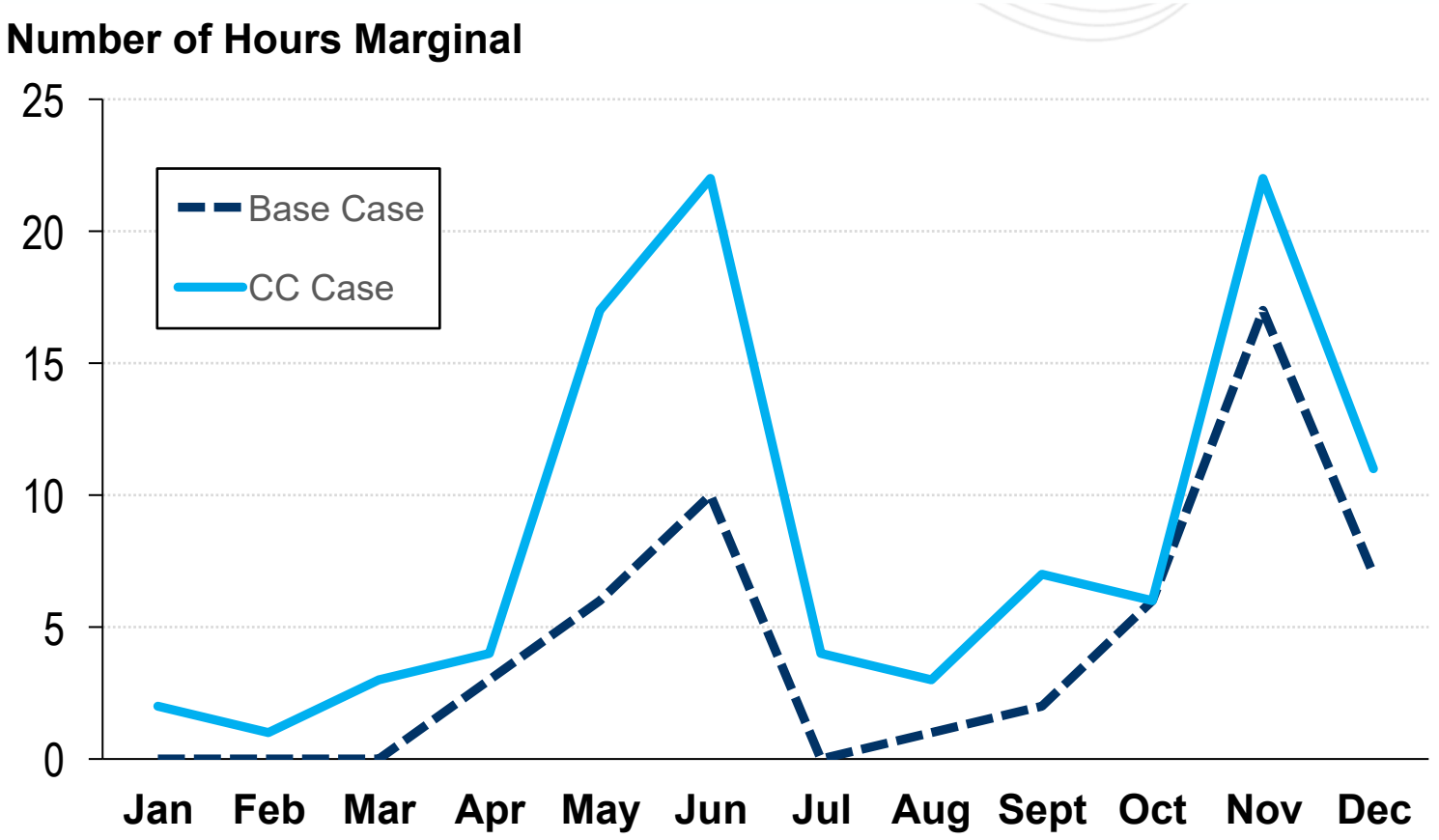
Difference between the Base and the CC Case in 2021: $1.00/MWh (3.6%)



Month	Base Case	CC Case	% Change
Jan	19.92	19.67	-1.3%
Feb	26.41	25.78	-2.4%
Mar	19.08	18.62	-2.4%
Apr	19.56	18.86	-3.6%
May	21.59	20.63	-4.5%
Jun	24.84	24.12	-2.9%
Jul	30.29	29.55	-2.4%
Aug	35.02	34.17	-2.4%
Sep	33.86	32.49	-4.0%
Oct	37.46	35.28	-5.8%
Nov	39.61	36.78	-7.2%
Dec	24.67	23.99	-2.8%
2021	**27.82**	**26.82**	**-3.6%**

Simulation Results – Total Hours Marginal CC Units

Increase in the number of hours that CC configuration units are marginal:

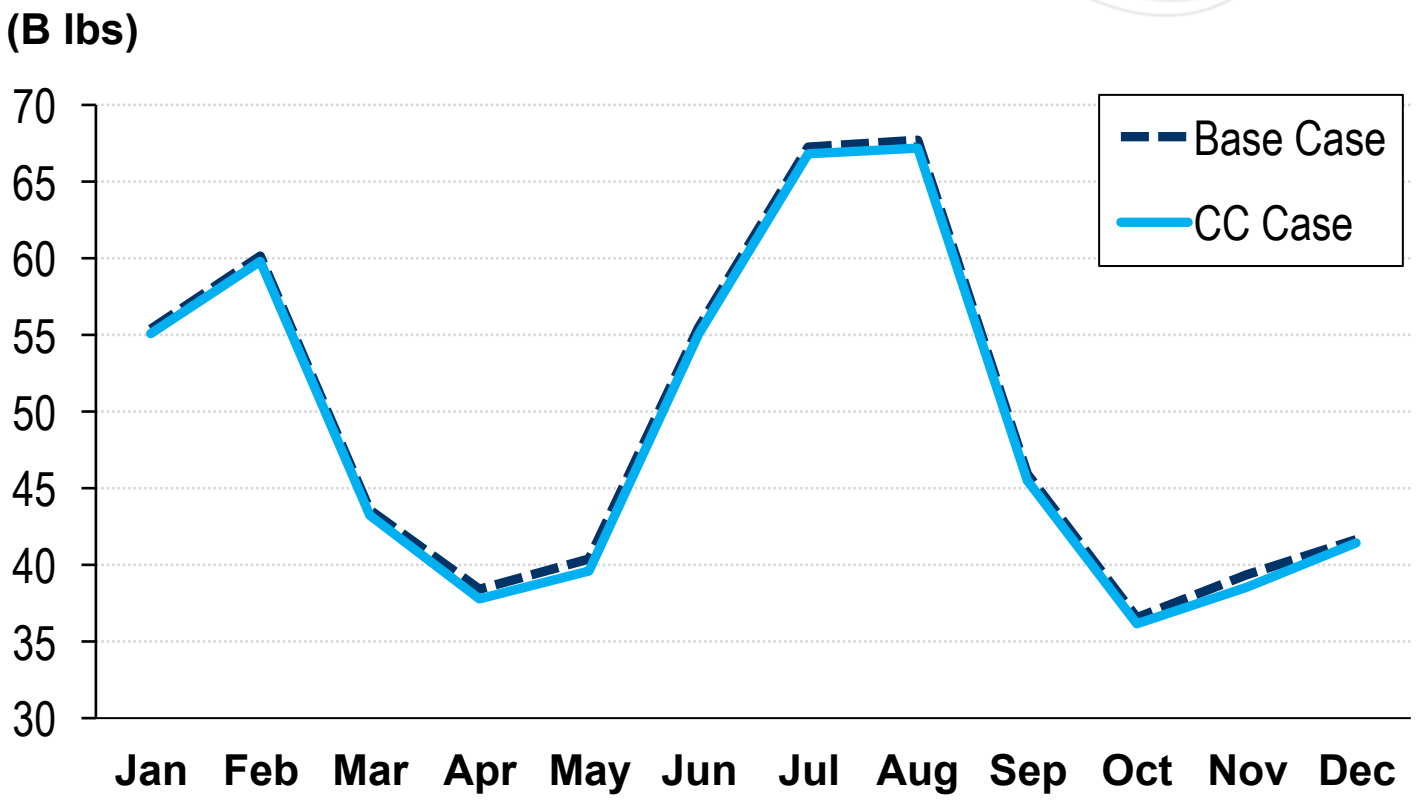


Month	Base Case	CC Case
Jan	0	2
Feb	0	1
Mar	0	3
Apr	3	4
May	6	17
Jun	10	22
Jul	0	4
Aug	1	3
Sep	2	7
Oct	6	6
Nov	17	22
Dec	7	11
2021	**52**	**102**

Simulation Results – Total RTO CO_2 Emissions

Decrease in the annual total RTO CO_2 emissions:

Difference between the Base and the CC Case in 2021: 5.64 Billion lbs CO_2 (1.0%)



Month	Base Case (Billion lbs CO_2)	CC Case (Billion lbs CO_2)	% Change
Jan	55.37	55.08	-0.5%
Feb	60.14	59.80	-0.6%
Mar	43.58	43.23	-0.8%
Apr	38.41	37.78	-1.6%
May	40.38	39.60	-1.9%
Jun	55.48	55.05	-0.8%
Jul	67.25	66.81	-0.7%
Aug	67.70	67.18	-0.8%
Sep	45.93	45.50	-0.9%
Oct	36.55	36.16	-1.1%
Nov	39.35	38.53	-0.5%
Dec	41.64	41.43	-0.5%
2021	**591.78**	**586.14**	**-1.0%**

MAJOR IMPROVEMENT IN DAY-AHEAD COMMITMENT PROCESS

Bid production cost savings of $150 million – $200 million/year with 40% of CC units modeled More savings expected with more CC units modeled	**Decrease in starts/stops by using lower configurations during lower demand hours**	**Better model of ancillary services** Different configurations can provide different amounts of ancillary services	**Better alignment with RT unit physical capabilities** Staged unit starts, stops, transition to higher configurations

More benefits expected in the future with the growth of renewables

- May be the primary marginal resource as renewables increase
- Helps minimize renewable curtailments
- Better management of fast ramp periods (i.e. duck curve)

Next Steps

Implement the MCR model for optimizing synchronous condensers in the PJM Day-Ahead Market

Additional enhancements to the unit commitment search and other aspects of the MCR model to further improve computational performance

Implement the MCR model in PROBE RAC that is used for PJM's Reliability Assessment and Commitment (RAC) run

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