Hybrid Resource Participation Model Benefit Assessment

Benefit Analysis of Enhanced Participation Models for the Independent Electric System Operator

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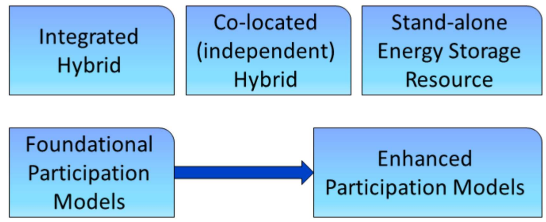
Outline

- Project Goals ad Motivation
- Simulation Results
- Other Considerations
- Conclusions and Next Steps

Project Goals and Motivation

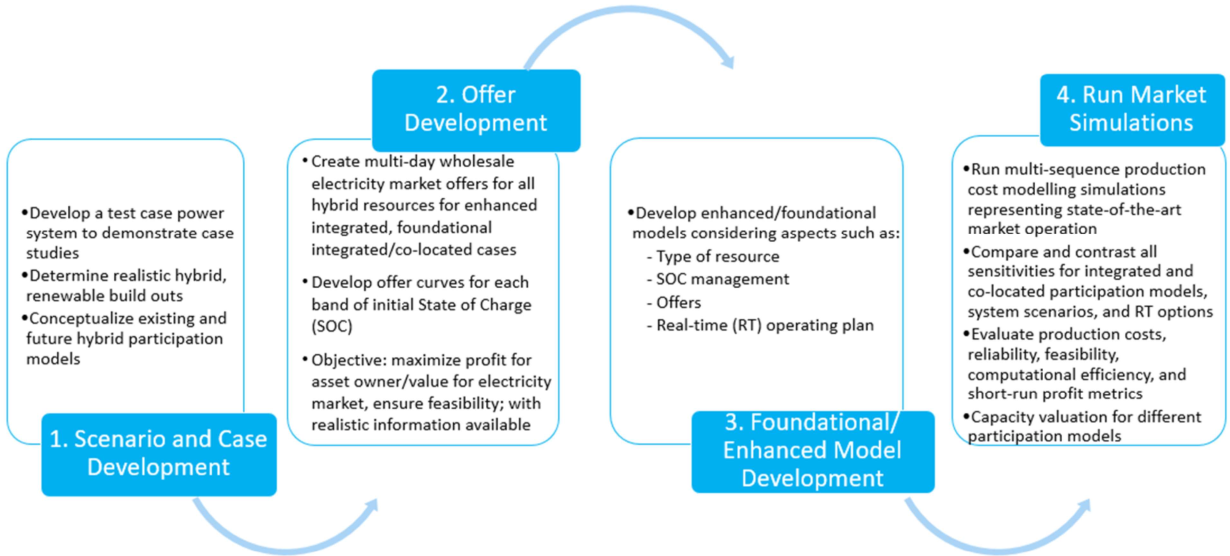
Exploring Hybrid Resource Participation Models

- **Project Motivation**
  - Hybrid/co-located resources are a potential resource to meet Ontario’s energy, capacity and grid services needs
  - IESO is evaluating the best ways in which the markets and operations can incorporate these technologies, primarily through foundational and proposed enhanced (enduring) models
  - There is a need to clarify how these different participation model options may impact various metrics
- **Project Goals**
  - Provide IESO with metrics that quantify advantages and disadvantages of different participation model options using realistic power market simulations
  - Identify general implications on reliability, economic efficiency, and asset profitability of high penetrations of hybrids
  - Share insights into other considerations regarding these participation models, including considerations that are difficult to quantify
  - Make recommendations for further examination



EPRI is working with IESO to provide both quantitative and qualitative assessments of enhanced participation models

Project Tasks



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Participation Models Considerations

- The participation models are developed by considering the following aspects:
  - Type of resource (co-located/integrated/stand-alone storage)
  - Number of resources: how many resources (separate) need to be modelled?
  - SOC management: If SOC constraints are considered in market engine?
  - Offers: single continuous offer or separate offers for each resource?
  - RT operating plan: which RT operating plan (Storage Follow (SF) or Hybrid Balance (HB))?

The challenges associated with understanding market participant behavior in simulation models leads to study approaches that may differ from the practical implementation of the participation models

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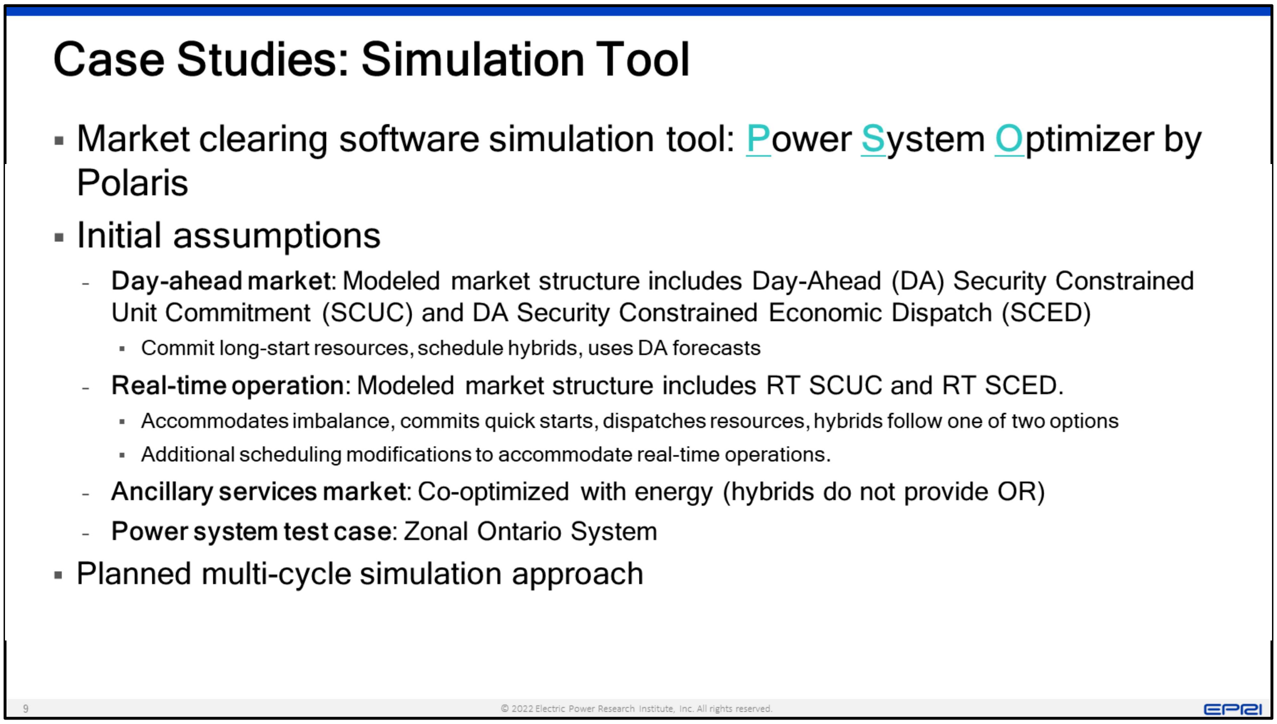
Storage Follow (SF): Schedules for the storage component of the hybrid resource will be interpolated from its day-ahead market schedules as long as SOC is at a level that it can do so.

Hybrid Balance (HB): Allow for the storage component to do whatever it needs to do to meet the DA hybrid schedule when there are VER forecast errors.

Case Studies: Introduction

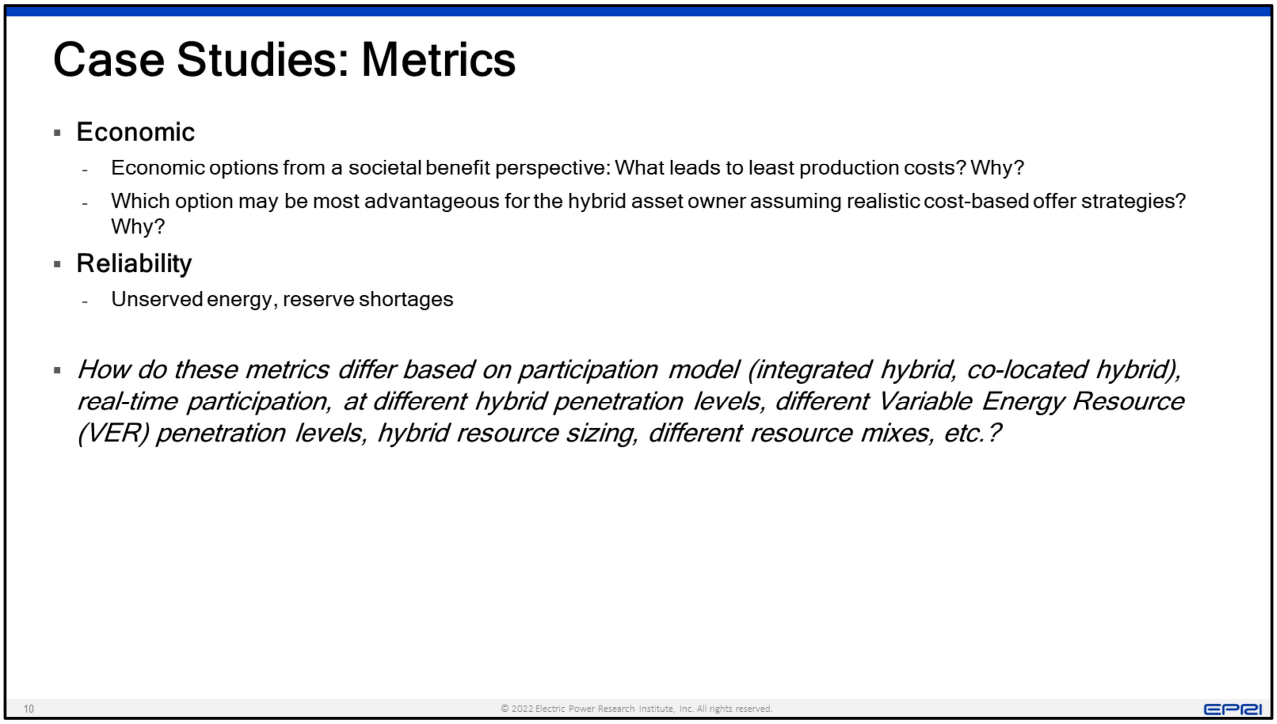
- Quantitative assessment of participation models in the energy market
  - Evaluate the key differences that alternative market designs for hybrid resources have on key metrics through modeling, simulation and analysis, while focusing impacts on day-ahead (DA) and real-time (RT) energy markets
    - Economic efficiency (operating costs/societal welfare)
    - Profits and incentives (individual resource/aggregate profits, revenue adequacy)
      - Day-ahead revenue, real-time revenue, two-settlement profit
    - Reliability of the system (power imbalances, reserve shortages)
    - Computational efficiency
  - Other anticipated impacts such as price setting, market settlements, make-whole payments, and market mitigation are out of scope for this specific study.



- To better understand the impact of hybrid resource participation options on operations, particularly with an increased penetration of VRE and hybrid resources, simulations across different timescales, dispatch strategies, hybrid configurations, and under different future potential generation mix scenarios will be carried out and analyzed in this study.

- First, the study team analyzes the impact of different participation options for hybrid resources on a representation of the Independent electricity System Operator (IESO) system on a yearly simulation case, i.e., the simulation time-frame for the case study results that follow is one year in a future weather year (late 2020s).

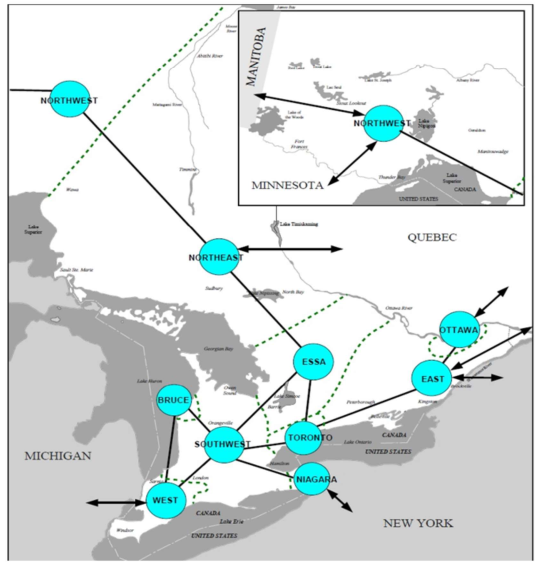
- The planned multi-cycle simulation approach includes a day-ahead market (DAM) with a three-day optimization horizon, which includes a 24-hour binding window and a 48-hour look-ahead (LA). In addition, the real-time market (RTM) has a 5-minute optimization horizon at a one-hour time resolution for simplicity and ease of implementation and interpretation.



- Economic efficiency (operating costs/societal welfare)
- Production costs – cost to supply Ontario's demand (energy + OR)
- Profits and incentives (individual resource profits, revenue adequacy)
    - Day-ahead revenue, real-time revenue, two-settlement profit
- Reliability of the system (power imbalances)
- Evaluation of participation model options on market schedule solution, pricing and settlement solutions, computational issues
- Impacts on economic efficiency, reliability and incentive compatibility

IESO Ontario Power System Overview

- Resource Mix:
  - Nuclear : 9,772 MW
  - Hydro : 10,557 MW
  - Thermal (gas/oil) : 10,886 MW
  - Wind : 4,644 MW
  - Solar : 2,349 MW
  - Demand response : 800 MW
  - Bio energy : 432 MW
  - Storage : 292 MW
- Max instantaneous load: 25,398 MW
- Model Features:
  - Zonal model: includes key interfaces, interchanges with external regions
  - Generating unit operating characteristics, Fuel prices
  - Load shapes, Wind facilities, Solar photovoltaic facilities
- Assumptions:
  - Pickering nuclear units are out of service



Summary of Study Cases

Scenarios were developed in March of 2022 for modeling purposes only; actual hybrid and storage volumes are expected to vary based on the outcome of procurements undertaken by the IESO. In October 2022, the IESO announced that it would procure up to 2500 MW of storage to be in-service by 2027.

Scenario	Description
High Hybrid Case	2000 MW total of new hybrid resources: - 750 MW effective capacity East zone new build solar hybrids (630 MW storage, 750 MW solar) - 500 MW effective capacity East zone new build wind hybrids (440 MW storage, 500 MW wind) - 750 MW of Southwest + West zone new build storage paired with existing wind
Medium Hybrid (+ Standalone Storage Case)	1000 MW total of new hybrid + 1000 MW of new standalone battery storage resources: - 375 MW effective capacity East zone new build solar hybrids (315 MW storage, 375 MW solar) - 250 MW effective capacity East zone new build wind hybrids (220 MW storage, 250 MW wind) - 375 MW of Southwest + West zone new build storage paired with existing wind - 650 MW of East zone new build standalone storage - 350 MW of Southwest + West zone new build standalone storage
Storage Only Case	2000 MW total of new standalone storage resources: - 1300 MW of East zone new build standalone storage - 350 MW of Southwest zone new build standalone storage - 350 MW of West zone new build standalone storage

Case Study Expected Learnings

Case	Compared with Case	Learning
Enhanced cases for all participation models	Foundational cases for all participation models	The benefits of moving toward more advanced participation models for IESO software systems.
Co-located hybrid participation models	Integrated hybrid participation models	The expected benefits and impacts in preferred participation option for hybrid resources.*
Medium hybrid cases (1000 MW of new hybrids + 1000 MW of standalone storage)	High hybrid cases (2000 MW of new hybrids)	Expected differences in comparisons when more hybrid resources are built and participating in the Ontario market.
Full integrated and full co-located (100% integrated or 100% co-located)	Mixed ratio cases (50% integrated + 50% co-located)	Implications of different impacts with different resource types competing to provide energy on the system.
Base case runs	Sensitivity cases	How variations on the technology (makeup of hybrid, storage duration) may influence results.

*This comparison is not a perfect comparison as there were assumptions made that impact results beyond the choice of participation model. An upcoming independent study by EPRI will include a comprehensive comparison between these two cases.

Simulation Results

1. Economic Efficiency and Cost Savings

Annual Operating/Production Cost

Integrated Hybrid Participation Models

Case	RT Operating Cost ($)	Delta Operating Cost[1] (%)	Delta Operating Cost[2] ($, %)
Base	1.187B	N/A	N/A
HH Foundational Integrated	1.142B	-3.78	N/A
HH Enhanced Integrated	1.142B	-3.79	-$173,065, -0.015%
MH Foundational$_1$ Integrated	1.167B	-1.64	N/A
MH Enhanced Integrated	1.167B	-1.69	-$70,367, -0.006%

[1] percentage difference in operating costs when compared to the base-case scenario without hybrids

[2] difference (in $ and %) in operating costs for enhanced participation option when compared to the foundational participation option.
MH Foundational$_1$ assumes the standalone storage are using the enduring storage participation model.

HH: High Hybrid; **MH**: Medium Hybrid

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This slide shows the operating or production cost differences across the difference cases in the **real-time scheduling process**. The day-ahead (DA) costs are typically not as consequential for conducting comparisons since the DA costs are not necessarily realized. Additionally, the RT production costs or system operating costs metric that is of focus to better understand the hybrid resource participation option economic efficiency implications do not include the costs of violations since such violation costs are subjective to the choice of penalty factors ($/MW) for the different violations; instead, the study team has included results that summarize the frequency of occurrences of such violations.

- In this case, the study team analyzes the impact of enhanced versus foundational participation options for high and medium hybrid integrated cases on a representation of the IESO system on a **yearly** simulation case, i.e., the simulation time-frame for the case study results is for the study year. Each unit commitment solution in the day-ahead market run and the real-time market run used a **MIP Gap of 0.1%.**
- **Delta operating cost[1]** denotes the percentage difference in operating costs when compared to the base-case scenario without hybrids.
- **Delta operating cost[2]** denotes the difference (in $ and %) in operating costs for enhanced participation option when compared to the foundational participation option.
- **MH Foundational[1] Integrated** model considers interim storage model for the storage

component of the hybrid resource and enduring storage model for the standalone storage in MH scenario.

- It is noted the differences in the operating costs are significantly small (can be neglected) when comparing the enhanced integrated and foundational integrated cases for HH scenario. Also, the MH enhanced integrated case shows only a slightly lower operating cost compared to MH foundational[1] integrated case. The differences observed are primarily due to the multiple optimization solutions possible within the optimality gap.

Annual Operating/Production Cost

Co-located Hybrid Participation Models

Case	RT Operating Cost ($)	Delta Operating Cost[1] (%)	Delta Operating Cost[2] ($, %)
Base	1.187B	N/A	N/A
HH Foundational Co-located	1.140B	-3.95	N/A
HH Enhanced Co-located	1.137B	-4.21	-$2.61M, -0.22%
MH Foundational$_1$ Co-located	1.157B	-2.53	N/A
MH Enhanced Co-located	1.155B	-2.69	-$1.34M, -0.11%

[1] percentage difference in operating costs when compared to the base-case scenario without hybrids

[2] difference (in $ and %) in operating costs for enhanced participation option when compared to the foundational participation option.

HH: High Hybrid; **MH**: Medium Hybrid

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This slide shows the operating or production cost differences across the difference cases in the **real-time scheduling process**. The day-ahead (DA) costs are typically not as consequential for conducting comparisons since the DA costs are not necessarily realized. Additionally, the RT production costs or system operating costs metric that is of focus to better understand the hybrid resource participation option economic efficiency implications do not include the costs of violations since such violation costs are subjective to the choice of penalty factors ($/MW) for the different violations; instead, the study team has included results that summarize the frequency of occurrences of such violations.

- In this case, the study team analyzes the impact of enhanced versus foundational participation options for high and medium hybrid integrated cases on a representation of the IESO system on a **yearly** simulation case, i.e., the simulation time-frame for the case study results is for the study year. Each unit commitment solution in the day-ahead market run and the real-time market run used a **MIP Gap of 0.1%.**
- **Delta operating cost[1]** denotes the percentage difference in operating costs when compared to the base-case scenario without hybrids.
- **Delta operating cost[2]** denotes the difference (in $ and %) in operating costs for enhanced participation option when compared to the foundational participation option.
- **MH Foundational[1] co-located** model considers interim storage model for the storage

component of the hybrid resource and enduring storage model for the standalone storage in MH scenario.

- It is noted that the operating costs are lower in HH enhanced co-located case compared to the HH foundational co-located case. The is because the enhanced co-located participation option has SOC management implemented through SOC constraints thus resulting in optimal SOC management followed by higher storage dispatch during critical periods compared to foundational co-located participation option.
- The MH enhanced collocated case shows lower operating cost compared to MH foundational[1] co-located case . The is because of the enhanced co-located participation option has SOC management implemented through SOC constraints thus resulting in optimal SOC management followed by higher storage dispatch during critical periods compared to foundational co-located participation option.

Annual Operating/Production Cost

Standalone Storage Participation Models

Case	RT Operating Cost ($)	Delta Operating Cost[1] (%)	Delta Operating Cost[2] ($, %)
Base	1.187B	N/A	N/A
Interim Standalone Storage	1.170B	-1.43	N/A
Enduring Standalone Storage	1.169B	-1.51	-$872,567, -0.074%

[1] percentage difference in operating costs when compared to the base-case scenario

[2] difference (in $ and %) in operating costs for enduring participation option when compared to the interim participation option.

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This slide shows the operating or production cost differences across the difference cases in the **real-time scheduling process**. The day-ahead (DA) costs are typically not as consequential for conducting comparisons since the DA costs are not necessarily realized. Additionally, the RT production costs or system operating costs metric that is of focus to better understand the hybrid resource participation option economic efficiency implications do not include the costs of violations since such violation costs are subjective to the choice of penalty factors ($/MW) for the different violations; instead, the study team has included results that summarize the quantity (MWh) or frequency of occurrences of such violations.

- In this case, the study team analyzes the impact of standalone interim versus enduring storage participation option on a representation of the IESO system on a **yearly** simulation case, i.e., the simulation time-frame for the case study results for the study year. Each unit commitment solution in the day-ahead market run and the real-time market run used a **MIP Gap of 0.01%.**

- **Delta operating cost[1]** denotes the percentage difference in operating costs when compared to the base-case scenario.
- **Delta operating cost[2]** denotes the difference (in $ and %) in operating costs for enduring storage participation option when compared to the interim participation option.

- It is noted that the differences in the operating costs are lower in the enduring standalone participation option compared to the interim standalone storage participation option. This is because enduring storage model has the SOC management implemented through SOC constraints thus resulting in optimal SOC management followed by higher storage dispatch during critical periods compared to interim storage participation option.

2. Revenue and Profits of Hybrid Resources

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Annual Sum of Revenues

Integrated Hybrid Participation Model

Case	DA Revenue ($)	RTM Revenue only ($)	Two settlement Profit ($)	Delta $ (%)
HH Foundational Integrated	85.43M	-3.65M	81.78M	N/A
HH Enhanced Integrated	85.78M	-3.81M	81.97M	0.19M (0.23)
MH Foundational Integrated	44.97M	-3.38M	41.59M	N/A
MH Enhanced Integrated	45.26M	-3.57M	41.69M	0.1M (0.24)

HH: High Hybrid; **MH**: Medium Hybrid

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- **Day-ahead revenue** takes the sum of the product of the day-ahead schedules and the day-ahead LMPs for each hour of the simulation.
- **Real-time revenue** takes only RTM LMP multiplied the difference of RT schedule and DA schedule.
- Finally, **two-settlement profit** takes the day-ahead revenue and then adds (subtracts) the product of positive (negative) deviation from the day-ahead schedules based on real-time schedule and the real-time LMP.

While the two-settlement profit result gives a good indication of actual profits received, the other two provide insights on what may be occurring in all of the simulation cases. These results do not include any make-whole payment settlements and are purely based on schedules and LMPs. They also do not factor in any additional costs of the storage component of the hybrid resource beyond the costs to charge energy (e.g., cycling and O&M costs are ignored and would essentially lower any profits further).

The enhanced integrated participation option results in greater amounts of revenue from the DAM, higher RT energy buy back, but resulting in overall higher two-settlement short-run profits compared to the foundational participation option for this study for both high and medium hybrid scenarios. This is primarily because of the slightly higher hybrid dispatch in enhanced participation option (3162 MWh over the period of one year) compared to foundational participation option. This difference is negligible and primarily arises due to the multiple optimal solutions possible because of the optimality gap considered (in this case 0.1%).

Annual Sum of Revenues

Co-located Hybrid Participation Model

Case	DA Revenue ($)	RTM Revenue only ($)	Two settlement Profit ($)	Delta $ (%)
HH Foundational Co-located	91.30M	-8.36M	82.94M	N/A
HH Enhanced Co-located	94.41M	-9.70M	84.71M	1.77M (2.13)
MH Foundational Co-located	46.90M	-3.11M	43.79M	N/A
MH Enhanced Co-located	47.38M	-3.24M	44.14M	0.35M (0.8)

HH: High Hybrid; **MH**: Medium Hybrid

The enhanced co-located participation option results in greater amounts of revenue from the DAM, higher RT energy buy back, but resulting in overall higher two-settlement short-run profits compared to the foundational participation option for this study for both high and medium hybrid scenarios. This is primarily because the enhanced co-located participation option has SOC management implemented through SOC constraints thus resulting in optimal SOC management followed by higher storage dispatch during critical periods compared to foundational co-located participation option.

Annual Sum of Revenues

Standalone Storage Participation Model

Case	DA Revenue ($)	RTM Revenue only ($)	Two settlement Profit ($)	Delta $ (%)
Interim Standalone Storage	7.32M	-0.411M	6.91M	N/A
Enduring Standalone Storage	7.57M	-0.340M	7.23M	0.32M (4.63)

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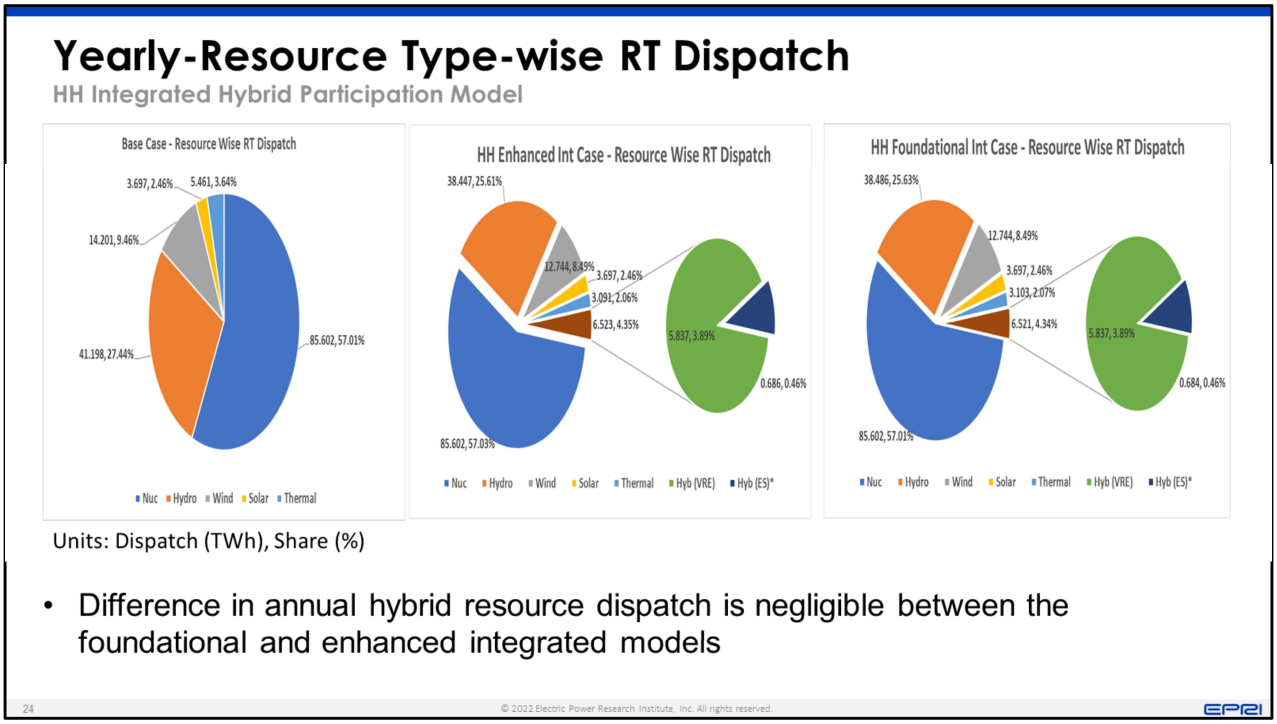
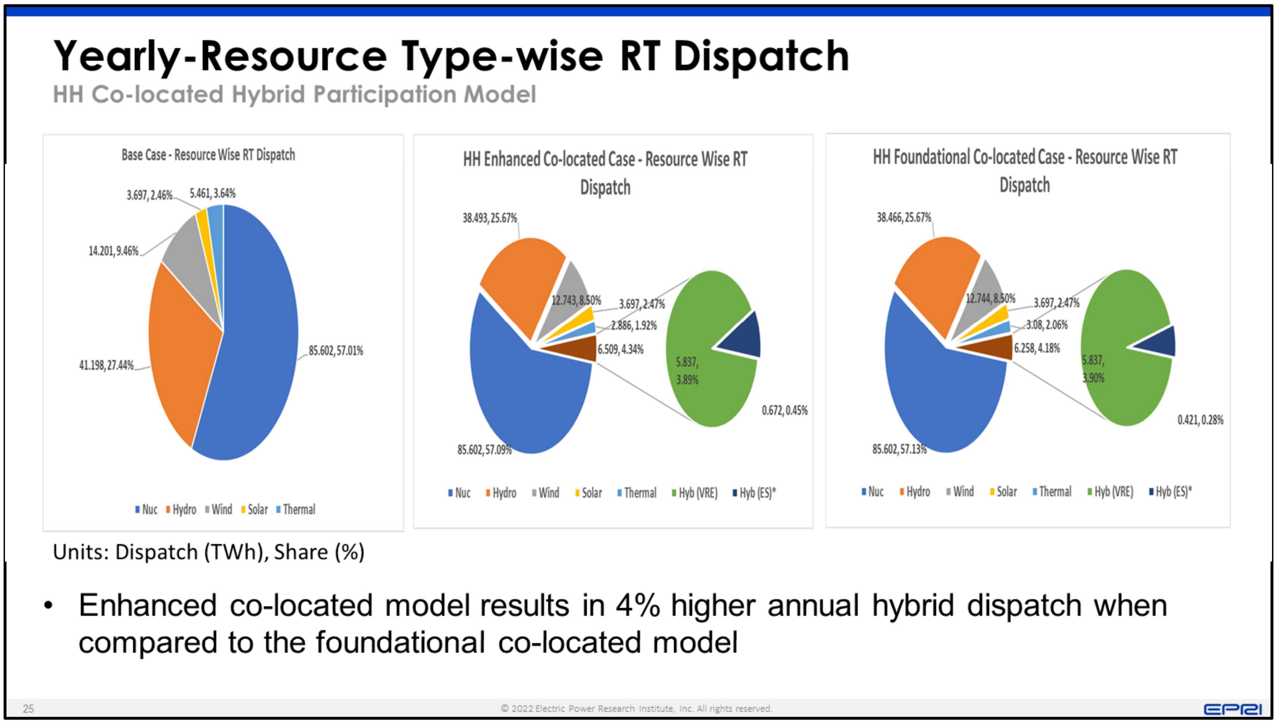
The enduring storage participation option results in greater amounts of revenue from the DAM, lower RT energy buy back, but resulting in overall higher two-settlement short-run profits compared to the interim storage participation option for this study. The is primarily because the in enduring participation option has SOC management implemented through SOC constraints thus resulting in optimal SOC management followed by higher storage dispatch during critical periods than the interim participation option. This translated to higher DAM revenue and lower RT buy backs in the enduring participation option compared to interim participation option.

3. Resource Mix Impact

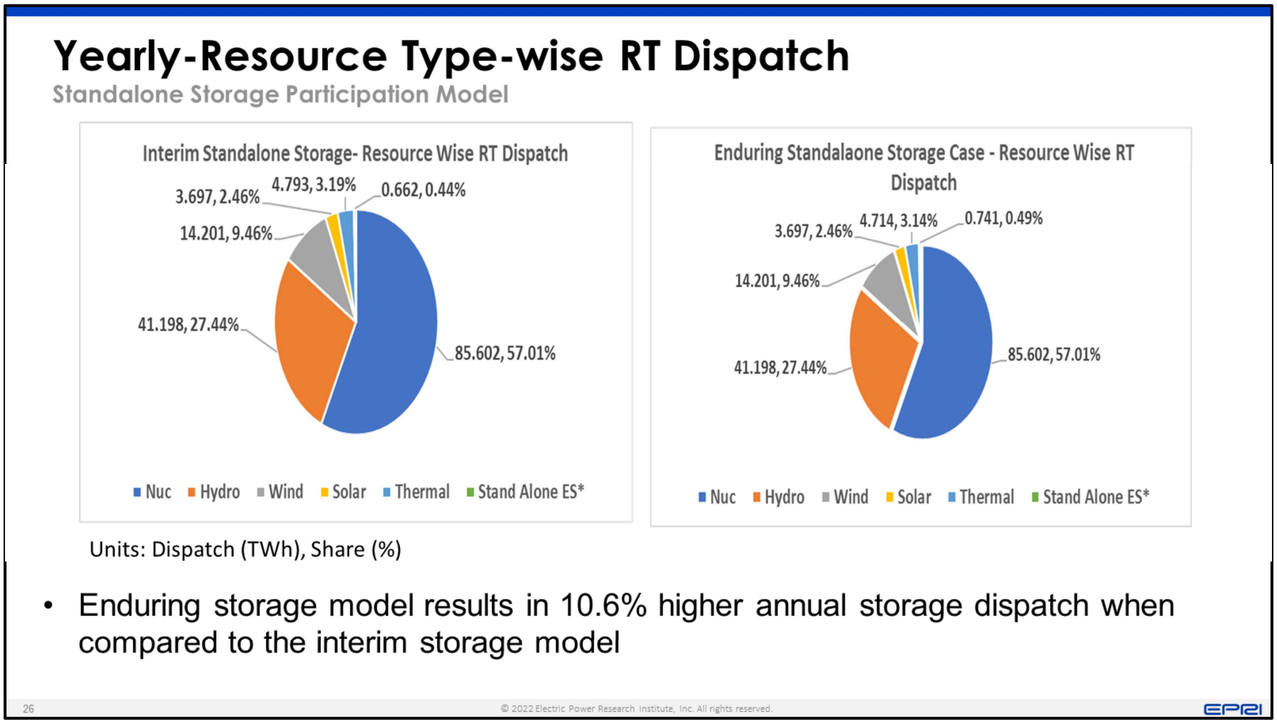


- This slide shows the resource-wise RT dispatch comparison of integrated participation options with the base case (without any hybrids). It is noted that in the foundational participation option, the aggregated hybrid dispatch is slightly lower, which results in higher thermal dispatch compared to Enhanced participation option. While the dispatch from nuclear, wind, solar are same in both enhanced participation option and foundational participation option. In general, hybrid resource participation has resulted in lowering the dispatch from expensive generators (thermal units).
- The change in the hydro dispatch in the enhanced and foundational integrated cases compared to the base case is because of the consideration of water rental tax. This leads to cheaper hybrid resources replacing hydro resources in certain intervals. However, the participation model designs have a negligible impact on the overall energy production of different resources across the year.
- Also, the dispatch from wind in the enhanced and foundational integrated cases is seen to be lower compared to the base case, this is because some existing wind resources are potentially hybridzied.



- This slide shows the resource-wise RT dispatch comparison of co-located participation options with the base case (without any hybrids). It is noted that in the foundational participation option, the aggregated hybrid dispatch is slightly lower, which results in higher thermal dispatch compared to Enhanced participation option. While the dispatch from nuclear, wind, solar are same in both enhanced participation option and foundational participation option. In general, hybrid resource participation has resulted in lowering the dispatch from expensive generators (thermal units). However, the participation model designs have a negligible impact on the overall energy production of different resources across the year.
- The change in the hydro dispatch in the enhanced and foundational co-located cases compared to the base case is because of the consideration of water rental tax. This leads to cheaper hybrid resources replacing hydro resources in certain intervals. However, the participation model designs have a negligible impact on the overall energy production of different resources across the year.
- Also, the dispatch from wind in the enhanced and foundational co-located cases is seen to be lower compared to the base case, this is because some existing wind resources are potentially hybridzied.
- It can be noted that the dispatch from hybrid resources is higher by about 4 % in

enhanced participation model compared to the foundational participation model. This can be attributed to the SOC management adopted in enhanced co-located model.



- It is noted that in the interim storage participation option, the storage dispatch is lower, which results in higher thermal dispatch compared to enduring storage participation option. The difference in standalone dispatch between interim and enduring model is because, enduring storage model which has the SOC management implemented through SOC constraints thus resulting in optimal SOC management followed by higher storage dispatch during critical periods compared to interim storage model.
- It can be noted that the dispatch from standalone storage is higher by about 10.6 % in enduring storage model compared to the interim storage model. This can be attributed to the SOC management adopted in enduring storage model.

4. Sensitivity Case Simulation Results

Evaluate the comparisons of foundational and enhanced participation models under various changes to the resources, their configuration, or operating plan to see whether conclusions hold true.

Annual Operating/Production Cost

Sensitivity on Storage to Generator Capacity Ratio

	15 %			85 %			100%		
Case	**RT Operating Cost ($)**	**Delta Operating Cost[1] (%)**	**Delta Operating Cost[2] (%)**	**RT Operating Cost ($)**	**Delta Operating Cost[1] (%)**	**Delta Operating Cost[2] (%)**	**RT Operating Cost ($)**	**Delta Operating Cost[1] (%)**	**Delta Operating Cost[2] (%)**
Foundational Integrated	1.146B	-3.43	N/A	1.142B	-3.78	N/A	1.141B	-3.85	N/A
Enhanced Integrated	1.146B	-3.45	-0.011%	1.142B	-3.79	-0.015%	1.141B	-3.87	-0.019%
Case	**RT Operating Cost ($)**	**Delta Operating Cost[1] (%)**	**Delta Operating Cost[2] (%)**	**RT Operating Cost ($)**	**Delta Operating Cost[1] (%)**	**Delta Operating Cost[2] (%)**	**RT Operating Cost ($)**	**Delta Operating Cost[1] (%)**	**Delta Operating Cost[2] (%)**
Foundational Co-located	1.144B	-3.62	N/A	1.140B	-3.95	N/A	1.139B	-4.04	N/A
Enhanced Co-located	1.142B	-3.79	-0.20%	1.137B	-4.21	-0.22%	1.136B	-4.31	-0.24%

- Increasing the ratio of storage capacity to VER capacity leads to lower production costs

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- One of the sensitivities considered in this study is by varying the ratio of storage capacity to VER capacity for the hybrid resource. Three ratio – 15%, 85% and 100% are considered. The ratios have been varied by changing the BESS capacity.

- This slide shows the comparison of real-time costs and the delta operating cost[1] (the percentage difference in operating costs when compared to the base-case scenario without hybrids) and delta operating cost[2] (the percentage difference in operating costs for enhanced participation option when compared to the foundational participation option), for different storage capacity to VRE capacity ratio cases. It is noted that the higher the ratio of storage capacity to VRE capacity, the lower are the production costs. This is because of the additional capacity value of storage added results in increased storage dispatch, thus increased in overall hybrid dispatch and reducing the thermal unit dispatch.

Annual Operating/Production Cost

Sensitivity on Battery Storage Duration Capacity

Case	2 Hour			4 Hour			8 Hour		
Case	RT Operating Cost ($)	Delta Operating Cost[1] (%)	Delta Operating Cost[2] (%)	RT Operating Cost ($)	Delta Operating Cost[1] (%)	Delta Operating Cost[2] (%)	RT Operating Cost ($)	Delta Operating Cost[1] (%)	Delta Operating Cost[2] (%)
Foundational Integrated	1.148B	-3.26	N/A	1.142B	-3.78	N/A	1.141B	-3.89	N/A
Enhanced Integrated	1.148B	-3.28	-0.012%	1.142B	-3.79	-0.015%	1.141B	-3.91	-0.020%
Case	**RT Operating Cost ($)**	**Delta Operating Cost[1] (%)**	**Delta Operating Cost[2] (%)**	**RT Operating Cost ($)**	**Delta Operating Cost[1] (%)**	**Delta Operating Cost[2] (%)**	**RT Operating Cost ($)**	**Delta Operating Cost[1] (%)**	**Delta Operating Cost[2] (%)**
Foundational Co-located	1.141B	-3.91	N/A	1.140B	-3.95	N/A	1.139B	-4.04	N/A
Enhanced Co-located	1.139B	-4.04	-0.19%	1.137B	-4.21	-0.22%	1.136B	-4.31	-0.25%

- Higher battery duration leads to lower production costs

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- One of the sensitivities considered in this study is by varying battery duration. Three types of batteries are considered – Short duration (2 hour), medium duration (4 hour), and long duration (8 hour).

- This slide shows the comparison of real-time costs and the delta operating cost[1] (the percentage difference in operating costs when compared to the base-case scenario without hybrids) and delta operating cost[2] (the percentage difference in operating costs for enhanced participation option when compared to the foundational participation option), for different battery duration cases. It is noted that the higher the battery duration the lower are the production costs (thus greater savings). This is because of the additional capacity value of storage resulting in from increased duration of the battery results in increased storage dispatch, thus increased in overall hybrid dispatch and reducing the thermal unit dispatch.

Other Considerations

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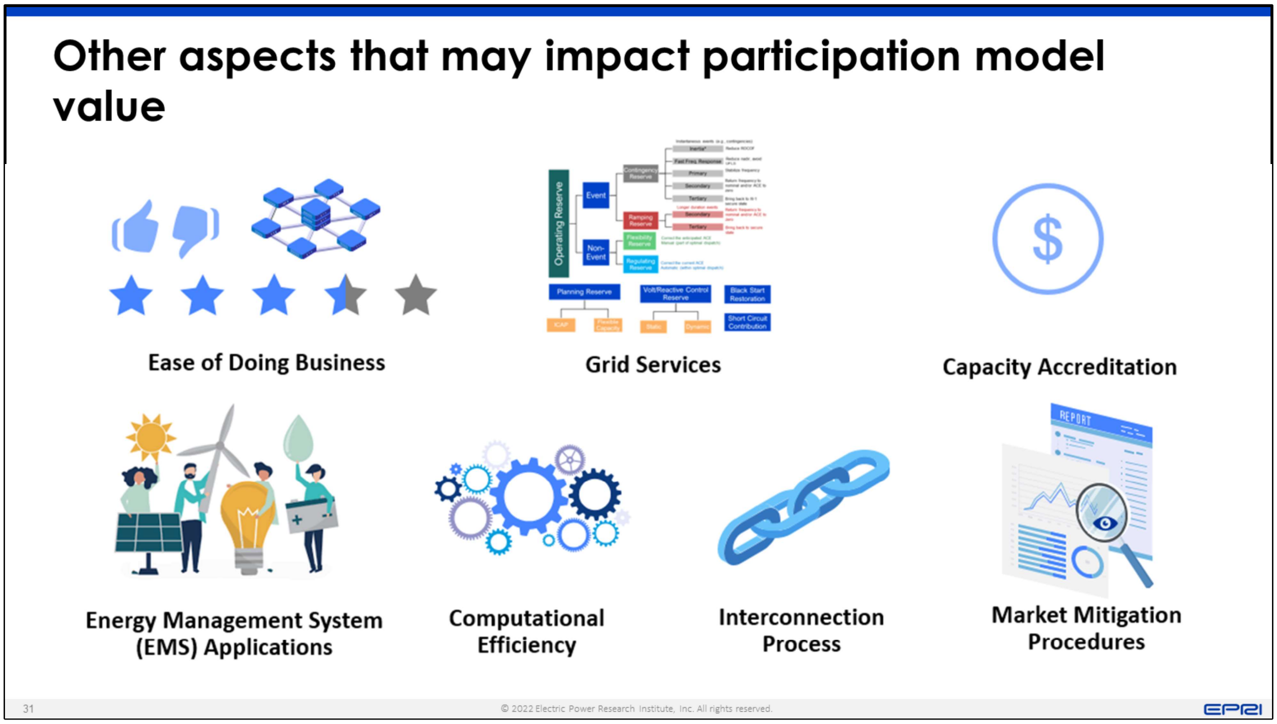


While the benefit assessment study focused on quantitative results of how the different enhanced participation models would impact the economic efficiency, reliability, and other metrics associated with the Ontario system and the facilities operating on the system, other metrics and aspects can be impacted by the development and use of these participation models. These additional considerations are often more difficult to quantify. However, they are important to take into consideration when evaluating the overall benefits of developing new participation models into the market. The seven shown here: Ease of doing business, grid services, capacity accreditation, energy management system applications, computational efficiency, interconnection process, and market mitigation procedures are those worth highlighting. However, others may be important as well. In the following pages, we share some thoughts on these additional considerations and how the different participation models may differ from these perspectives.

Ease of doing business

- Participation models that make it easier for market participants to interface with the IESO are desirable. What makes participation easier is somewhat subjective depending on the market participant and their experience. The following characteristics can be considered. This ease of business is viewed from the market participant perspective.
- The **fewer number of interfaces** between the market participant and the IESO may be preferred to simplify the participation interface. The enhanced integrated hybrid model, with just one interface for offer provision and settlement determination allows simplification. In general, the enhanced models may improve this characteristic by combining charging and discharging and allowing for reduced number of interfaces.
  - The fewer number of interfaces may mean fewer data parameters to provide to the IESO or telemeter. If the data parameters are redundant, then this duplication of effort may negatively impact ease of business. This may also mean fewer instrumentation (metering, telemetry) , but this depends on the requirements that may be in place.
- Anecdotal evidence from a subset of market participant discussions have described ease of business also referring to the **flexibility** that the asset owner has in **developing the offer strategy**. Internal facility characteristics are not always possible to represent in the IESO market clearing software, but these can be considered in the offer bid that the market participant provides. With fewer constraints and parameters that may affect offer selection, this may allow the market participant to better achieve desired result with the offer that is provided.
  - Enhanced integrated hybrid may show benefits by allowing selection of energy schedules through simple price-quantity paired offers.
  - With the **enhanced integrated hybrids**, the asset owner can use internal capabilities that fully reflect its knowledge of resource capabilities.
- Other participants have described ease of business by allowing the **ISO to determine the optimal schedule**. If the participation model reflects known parameters in the market clearing and the cost minimization objective of the IESO's market clearing software generally leads to profit maximization of individual assets (under convex assumptions), then this may be preferred.
  - Under the **enhanced co-located hybrid** participation model, the market participant can provide its starting state-of-charge, utilize an IESO VER forecast, and other parameters, and the IESO will dispatch it in a way that would reflect cost minimization and profit maximization under the forecasted conditions.
  - With this in mind, the market participant does not need a complex offer strategy to earn profit, only to provide its true parameters. For many market participants, this may prove beneficial in ease of doing business in the energy markets.

Grid services (market-based)

- In Ontario, there are several bulk system grid services that are necessary to ensure reliability of the system. Some of these services, such as operating reserve, are procured through ancillary service markets. Others are either contracted, provided cost recovery, or not compensated. For each of these services, there may be differences in the benefit to the system or to the market participant depending on the participation model that has been developed or chosen by the market participant.
- In the quantitative studies of this project, while ancillary services are modeled, the hybrid resources are not eligible to provide those services in any of the simulation runs. It is important to note that this was a modeling choice, but that in practice these resources are technically capable of providing services and do provide these services in many jurisdictions around the world.
- Hybrid resources under any participation model may **earn additional revenue** from providing operating reserve in the IESO market. **Total system costs can also be reduced** when hybrid or storage resources provide operating reserve, as they would be selected to do so when they are more cost effective than other resources competing to provide the corresponding service.
- Each of the enhanced models may provide benefits by allowing storage, and the storage component of the hybrid resource, to be able to provide a reserve service that spans the capacity of both its charging and discharging range.
  - For example, a hybrid resource that is charging from the grid at full charge capacity with energy being injected from the generation component of the hybrid, can stop charging and discharge if a contingency event were to occur. This would show that its operating reserve capability is the **sum of its maximum charging and maximum discharging**. This eligibility may be impacted if the charging and discharging are separate resources as is the case in the foundational participation models.
- To maintain reliability and security of the power system, IESO may need to ensure any resource providing operating reserve has the capability to do so should it be called upon. The IESO may need to know what the true capability of the resource is to rely on its contribution to operating reserve.
  - In this case, the **enhanced co-located hybrid model**, which would have information on the forecasted variable energy resource production and the state of charge of the storage asset, would benefit in that it allows the IESO to have the confidence that the power and energy is available for the resource to provide operating reserve if needed and sustain output for as long as is necessary until it is no longer needed. Other participation models, including self-scheduling of reserve, can lead to infeasible operating reserve schedules, which can put the system at risk.

Grid services (non-market based)

- Regulation, reactive support and voltage control, and black-start capability are contracted in Ontario and are provided by resources throughout the Ontario system.
  - Storage resources are currently allowed to provide regulation service as a self-scheduled entity but are not eligible to provide both energy/operating reserve and regulation (i.e., they can only provide regulation).
  - Although technically capable, variable energy resources are mostly not eligible to provide regulation and other active power services in most regions. This means that regulation from the variable energy resource component under the enhanced co-located participation model would be limited. It is unclear how the VER component may provide regulation in the integrated hybrid model if the IESO has limited knowledge of how it is being provided from the integrated facility.
- Regulation and primary frequency response are active power services, similar to operating reserve. While less than that needed for operating reserve, these services do require a certain amount of energy for the resource to sustain output in case needed.
  - The enhanced co-located participation model would allow the IESO to understand the capability through its state-of-charge parameter that is used through telemetry and within the market clearing software.
  - This participation model may allow for storage and hybrid resources to provide regulation and energy/operating reserve **simultaneously**, so long as the same capacity is not double counted.
- Since black start and voltage control are not forms of reserve, these may have less differences across the various participation models
  - Hybrid resources may lead to reactive power "fighting" whereas one resource supplies reactive power while another resource consumes it, while attempting to control voltage. This may be the case in instances where the individual co-located hybrid resource components have plant controllers owned by different owners.
  - There is benefit for a coordinated response from the entire hybrid facility (using a single plant controller that helps avoid 'fighting') as opposed to individual responses from each technology. This aligns with the enhanced integrated participation model; however, given voltage control is not part of market clearing, the participation models are somewhat decoupled from the responses that the resource provide outside of the market.
  - Black start qualification will require greater amounts of energy for the resource to sustain output in case needed, so shorter-duration storage resources and variable energy resources may not be technically capable of satisfying the eligibility requirements.

Capacity Accreditation

- Capacity is another grid service that is often separated from those discussed previously as it is primarily used for longer term system planning.
- Capacity service is important as the sum of resource capacity determines how the IESO will be able to meet the peak conditions of the future.
- Capacity accreditation is the quantity that a resource contributes to the peak conditions to meet resource adequacy requirements
  - For example, many regions target involuntary load shedding to occur no more than 1 day in a 10-year span
  - Capacity accreditation is a value that is less than or equal to 1. Resources who have greater availability have higher accreditation. Resources with lower availability (e.g., higher forced outage rates) have lower accreditation.
- Capacity accreditation rules for storage and hybrid resources are complex as it is not only about forced outage rates, but unavailability due to uncertainty in the wind/solar energy and uncertainty due to lack of state-of-charge.
  - Some regions have simple accreditation based on duration of storage; Others use Effective Load Carrying Capability (ELCC)
- Interconnection limit, local generation availability, storage duration, and anticipated portfolio all affect capacity credit.
- The capacity accreditation methodology proposed in this study is different from the methods currently used by IESO.

TABLE 4
Two Options for Hybrid Resource ELCC Calculations

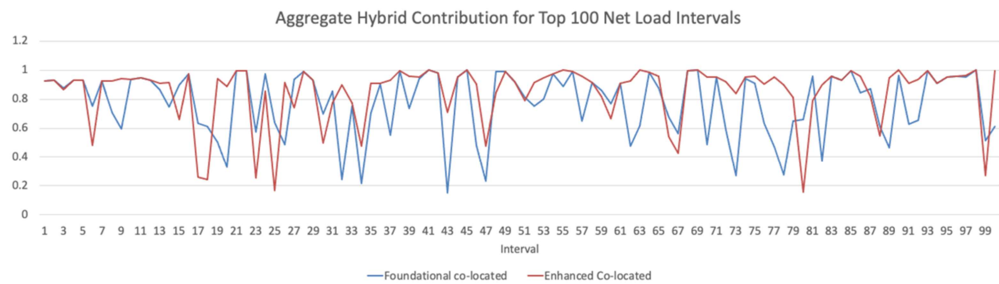
OPTION A	OPTION B
Individual Resource Accreditation	**Aggregate Resource Accreditation**
Is a sum of ELCC individual hybrid resources, capped at the point of interconnection	Evaluates the hybrid plant ELCC at the aggregate plant level as a unique resource
Advantages	
• Is simple to implement and understand • Does not require unique modeling for all hybrid configurations	• Evaluates the specific characteristics of the hybrid plant • Considers charging constraints • Considers benefits of higher inverter loading ratios and DC coupling
Disadvantages	
• Does not account for portfolio effects at the plant level • Does not consider charging constraints • Does not consider benefits of higher inverter load ratios and DC coupling	• Requires individual analysis of each hybrid resource on the system • Is computationally burdensome and analytically time-consuming

Note: ELCC = effective load-carrying capability.
Source: Energy Systems Integration Group.

Capacity Accreditation Methodology

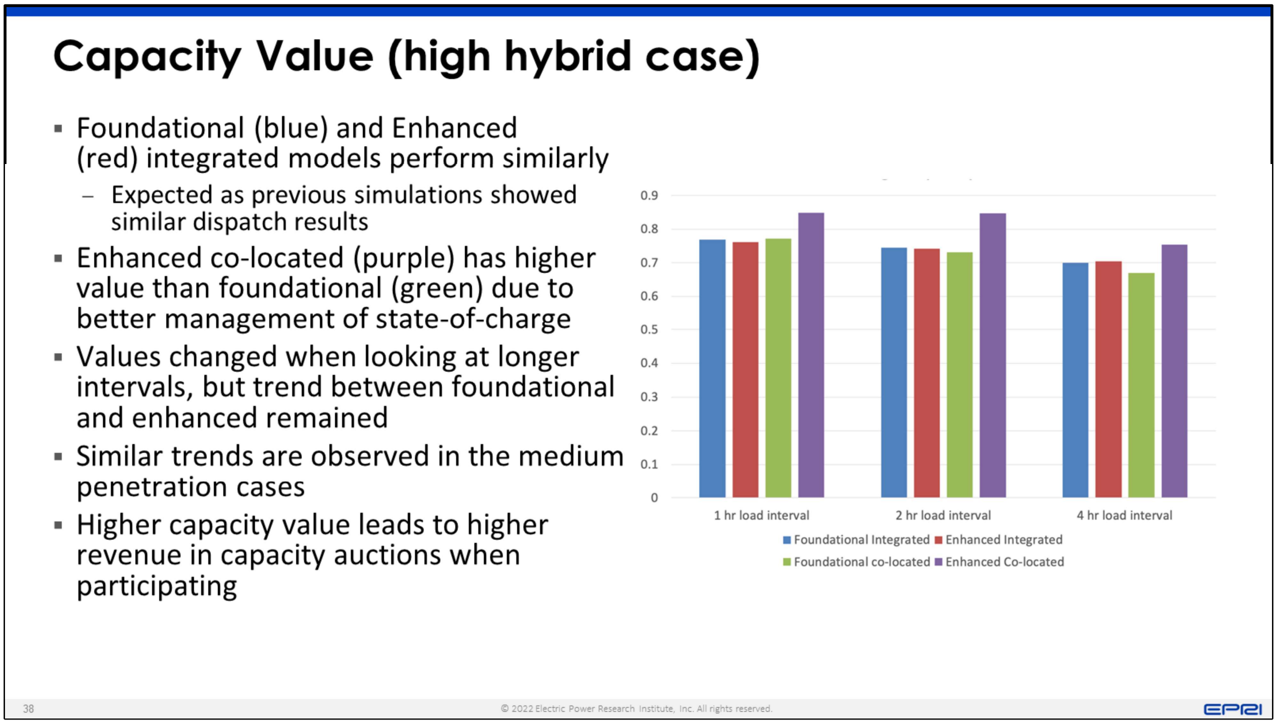
- **Goal**: Quantify capacity accreditation using a *simplistic approach* to provide further insights to the IESO around the impact of participation model on capacity credit of hybrid resources
  - Show how different participation models impact the ability for hybrid resources to provide energy during high times of system stress
- Analysis using existing simulations performed as part of this study
  - **NOT** a comprehensive resource adequacy (RA) study, no outage draws, not ELCC
  - The method is analogous to how ELCC may be determined but for a single *deterministic* scenario based on the simulations
  - ELCC studies would use hundreds more scenarios and evaluate the additional load that can be met under the same reliability
  - Method looks at availability under the top 100 netload intervals, as there is no loss load in the single scenario, this is an approximation
  - Equal weighting to all 100 net load intervals
- Values between zero and one
  - Zero: not providing energy nor capable of providing energy (out of state-of-charge)
  - One: providing nameplate interconnection capacity or capable of providing nameplate interconnection capacity
  - Sum up across all 100 intervals
- Length of top intervals adjusted
  - In addition to top 100 hourly intervals, the team also looked at the top 50 2-hour periods and top 25 4-hour periods to ensure that any state-of-charge limitations were being represented in the results

Capacity Values by Resource and Critical Periods (high hybrid case)



- Enhanced model has higher capacity credit compared to foundational model for co-located case
- Allowing the market clearing engine to optimize with SOC limitations enforced better positions the facility for meeting critical time periods
- Comparison with foundational and enhanced integrated hybrids showed negligible differences

This chart shows the aggregate of all hybrid facilities and their contribution to each of the top 100 net load intervals. Again, a value of 1 means that they provided or could have provided if directed to, their full nameplate capacity during that particular hour. A lower number that either because of lack of energy from the generation component or lack of state-of-charge from the battery component, they were not capable of providing that amount, but some lesser amount. The primary difference between the enhanced and foundational co-located cases is the SOC construct in the optimization for the enhanced case. Allowing the operator to monitor and consider SOC yields more efficient utilization of the storage components. Extra capacity is withheld for dispatch during these peak netload intervals, resulting in a higher aggregate capacity value (0.85) compared to the foundational case (0.77).



Storage assets have a unique operating characteristic in that any dispatch decision being made now will directly impact the ability to provide energy in the future. In order to capture this type of constraint, 2 additional sensitivities were performed for this analysis. We considered 2 additional scenarios. In the first, the load intervals in the year are grouped into 2 sequential interval pairs and the top 50 of these grouped intervals is considered. In the second, the load intervals are grouped into 4 sequential interval pairs and the top 25 of these grouped intervals is considered. As expected, extending the interval reduces the capacity value but similar trends are observed in all scenarios.

Since the only difference between the enhanced and foundational integrated models is the shape of the offer/bid curve, we expect a similar behavior from both. The foundational co-located case shows a lower capacity factor compared to the foundational integrated case. Each of these cases has a different real time objective. In the co-located case, the storage component must strictly follow the DA dispatch schedule. For the integrated case, the storage component is allowed to redispatch in real time to correct forecast errors caused by the renewable energy component. The ability for the storage component to adjust its dispatch in real time allows it to take advantage of times when the renewable component is under-forecasted in the day-ahead. For example, on Aug 4, there is only approximately 3.9 GWh of renewables from the hybrid plants forecasted in the day ahead. However, in real time, the actualized energy from these resources is 4.43 GWh. By allowing the storage components to absorb this extra energy, the capacity factor is increased (blue) compared to the case where it was not allowed to do so (green) when compared of multiple intervals (middle and right).

Energy Management System (EMS) Applications

- EMS applications, including real-time contingency analysis, state estimation, automatic generation control, and multiple control room displays and interfaces.
- Most of these studies include the representation of individual units.
- Combined representation of pseudo facilities that are in fact the same resource provides **benefits** to EMS applications (**all enhanced models**).
- Combining facilities that have different characteristics may not be necessary for EMS applications (**enhanced co-located vs. enhanced integrated hybrids**)
- Currently there isn't a dedicated participation model or market clearing software design for hybrid resources that appropriately accounts for the individual and combined modelling characteristics of the hybrid resource components.

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Computational efficiency implications

	Day-Ahead Solve Time (min)	Real-Time Solve Time (min)
Base	21.91	230.41
Foundational Integrated	28.47	249.12
Enhanced Integrated	27.23	244.35
Foundational Co-located	30.21	272.63
Enhanced Co-located	33.77	281.34

- More resources participating in the market has impact on solve time
- Cases with co-located participation models have larger impact than those without

- The total solve time (sum of day-ahead and real-time) are higher for the hybrid cases (enhanced and foundational) compared to the base case because the storage component optimization is additionally considered in hybrid cases. The real-time solve time are much higher than the day-ahead solve time because of the larger number of RT intervals arising due to considering 5-min real-time horizons.
- The integrated/co-located participation option has higher solve time because it has both SOC constraints modeled (for the co-located resources) and at the same time it employs two different real-time participation plans (SF and HB in the same model) as compared to using only one real-time operating plan with fully co-located (SF plan) or fully integrated cases (HB plan).

Interconnection Process

- The three main elements of the interconnection process that bear upon the success of co-located and integrated hybrid resource projects:
  - the clarity and consistency of interconnection procedures;
  - requirements for adding to or changing projects in the queue;
  - and modeling and data approaches.
- Existing generation sites can be hybridized with storage without major upgrades necessary on the transmission system as the total injections are not expected to increase. They may request interconnection service that is less than the sum of the capacity of both resources.
- It important to appropriately address the following challenges: (1) interconnection customers' desire for flexibility in interconnection requests; (2) material modification rules that do not allow for the addition of storage facilities to generation projects already in interconnection queues without the loss of queue positions; and (3) interconnection studies that may not appropriately model integrated hybrid resource operation.
- The studies that are performed during the interconnection process may require differences in the study of hybrid resources, especially the ability to charge. However, the study team is not aware of the need to study the resource interconnection differently depending on the anticipated participation model it will use in the energy market. Thus, there is no material difference in the interconnection process between foundational and enhanced participation models.

Market Mitigation Procedures

- Any offers provided by storage or hybrid resources can be based on a multitude of things: (1) cost of charging power, (2) opportunity cost of discharging now vs. saving energy for later, (3) opportunity costs across energy and reserve products, and (4) degradation.
- Market monitoring and mitigation can evaluate offers to ensure that the market participant does not have market power and is not gaming.
  - Market power can include both physical and economic withholding
- In dynamic electricity markets, the opportunity cost value can change rapidly, and one owner's calculation may differ from what a market monitor assumes.
  - The current ISO provisions for opportunity costs in resource reference levels are inappropriate for hybrid resources and the standalone storage resources, which is likely to misestimate the actual opportunity costs of such resources.
- In enhanced co-located participation model, the opportunity cost within the day, and the cost of charging power **can be automatically determined** in the day-ahead market. In foundational models and the enhanced integrated hybrid model, they are not.
  - Market power mitigation rules should be able to differentiate between instances of genuine anti-competitive physical withholding and a hybrid resource optimizing the joint operation of its component resources.
  - This may be easier with the enhanced co-located participation model
- ISOs, market monitors, and regulators must develop market power mitigation rules related to reference levels, physical withholding, and other provisions in a manner that mitigates market power and also appropriately reflects the incentives, short-run marginal costs, and optimal operation of hybrid resources.

Conclusions and Next Steps

Conclusions and Key Takeaways

- Cost savings and economic efficiency benefits **are observed with the addition of hybrid and standalone storage**, regardless of the participation model used. Savings are greater with more of these resources added.
  - Savings are between **2%** and **4%** of total costs for 1,095 MW and 2,160 MW of hybrid resources, respectively.
- Cost savings and economic efficiency benefits are **further observed** when the enhanced participation models are used for **co-located** and **standalone storage** when compared to the foundational participation models for those same types.
  - These additional savings are modest, with **$1.6M per year** with a medium addition of hybrids, and **$2.6M per year** with a high addition of co-located hybrid resources.
  - The use of state-of-charge limits within the market clearing model **more efficiently operate** the resources in enduring storage and enhanced co-located models.
- System cost savings are observed to be **minimal** for resources that transition from foundational to enhanced **integrated hybrid** participation model
  - The main difference of moving to a combined set of offers (i.e., no change in SOC representation) has little effect on the market clearing, especially as it may be **unlikely** that a hybrid would have segments of their offer that include **both** charging and discharging (i.e., same costs for charging and discharging)
  - If this change in participation model leads to a **different** offer strategy for the integrated hybrid resource, the changes may be more **measurable**.
- Similarly, the difference in sum of individual revenues between Enhanced and Foundational Integrated resources is **minor,** whereas the revenue of resources using the **Enhanced Co-Located Participation Model** is in aggregate about **$1.75M** higher across the year than the same case when resources participated using the foundational co-located model.

Conclusions and Key Takeaways

- In general, the participation model designs have a **negligible impact** on the **overall energy production** of different resources across the year
- While a more sophisticated real-time bidding will occur in practice, the simulations showed that it **may not necessarily be beneficial** for hybrids to **balance out** the full hybrid's day-ahead schedule for each hour when there may be imbalance due to VER forecast error
  - Balancing out the schedule for the current interval, **may prevent it from meeting its day-ahead schedule later in the day**, when it may be more helpful for the system
- **Trends were similar** in various **sensitivities**. When batteries **have lower energy storage duration**, the enhanced co-located participation model, while still performing better than the foundational co-located model, **has a lower production cost reduction** than when the storage **has higher duration capacity**.

Conclusions and Key Takeaways

- Ancillary services can be important consideration albeit not studied in detail here. Advanced participation models can allow for hybrids to participate in ancillary services and provide a **service across its charging and discharging range**
  - Ability for the IESO to monitor state-of-charge in market clearing can ensure that the facility has sufficient energy to provide operating reserve if required to do so. This can allow improved value stacking for these resources.
- While a full resource adequacy study was not performed here, it appears that the **enhanced co-located participation** model can lead to **higher** capacity contribution compared to other participation models.
- The enhanced co-located participation model **adds computational complexity** to the market clearing software compared to foundational co-located and enhanced/foundational integrated models, primarily **due to the SOC time-coupling constraint**. Adding more hybrids generally can increase solve time as well.
- **Other aspects** of IESO and hybrid resource interactions are **important to consider** even if they do not have a way to quantify how participation models may benefit. These include ease of business, EMS applications, non-market services, interconnection, and market monitoring and mitigation.

Future Work

- Analysis of this work can provide information for determining the benefits of advanced participation models, but additional analysis can help IESO and its stakeholders to better prepare for incoming hybrid and/or standalone storage resources.
- Conducting analysis of additional scenarios and sensitivities to quantify different benefits of the various participation models.
  - Sensitivities could include change in natural gas prices (given assumptions were based on lower prices than today), change in build out and retirements, interchange effects, electrification impacts to load, and other scenarios.
- Evaluation of real-time offer strategies and how these may impact reliability and economic efficiency.
- Evaluation of ancillary service provision from these resources and how this may impact reliability and economic efficiency.
- Further enhancements to these participation models, such as how they would incorporate separate costs like battery degradation cost associated with storage resources.

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