AGO Alternative Storage EAS Revenue Estimates

NEPOOL Markets Committee

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AGO review of the Storage ORTP finds three shortcomings each of which inflate the ORTP

1. **Losses.** CEA assumes all storage inefficiencies are incurred on discharge.
   - Not how batteries work electrochemically; losses occur on charge and discharge.
   - This assumption will (a) reduce effective battery size; (b) require excessive derating for qualification; and (c) reduce EAS revenues.
2. **Sizing.** CEA relies on an uncommon 150 MW-ac / 300 MWh-dc (258 MWh-ac) battery rating. Extreme assumption about losses reduces effective energy-rating below a reasonable level.
3. **Dispatch.** The deterministic spreadsheet model CEA relied on may be easy to understand, but yields materially lower EAS revenues compared to alternative techniques.

Effect: These shortcomings drive unreasonably low EAS revenue offsets.

CEA assumptions minimize the effective size of a battery with a "2-hour duration"

- CEA adopts an uncommon battery specification with an AC-rating for capacity but DC-rating for energy (150 MW-ac / 300 MWh-dc).
  - The extreme losses assumption results in a 258 MWh-ac effective output.
- Alternative assumptions would result in larger battery and higher revenue.

	Bought from Grid	*Charging Losses*	Held in Cells	*Discharge Losses*	Returned to Grid	% of CEA Rating
	MWh-ac		MWh-dc		MWh-ac	
All Losses on Discharge	300.0	*0.0*	300.0	*-42.0*	258.0	
Symmetric Losses	323.5	*-23.5*	300.0	*-21.8*	278.2	108%
All Losses on Charge	348.8	*-48.8*	300.0	*0.0*	300.0	116%
AC Rated Battery	348.8	*-25.3*	323.5	*-23.5*	300.0	116%

- Battery size also affects derating for qualification, which is based on maximum output over 2 hours. Higher MWh-ac rating = higher qualification.

Deterministic modeling does a poor job of estimating revenues for energy storage

- Modeling energy storage is difficult given lack of benchmarks and quickly evolving marketplace.
- Transparent assumptions improve ORTP process.
- EAS revenue estimates should reflect earnings associated with a reasonably competent developer operating in the assumed markets.
- CEA revenue estimates do not reflect what a reasonably competent storage resource could earn in the energy and TMSR markets.

Issues with deterministic dispatch of energy storage are intrinsic to the tool itself

- Issues include (but are not limited to):
  - Charging only in fixed windows (not necessarily periods when prices are expected to be lowest).
  - Discharging when prices reach a fixed, very high threshold (not adjusted for time-of-day or season). Often misses higher values later in the day.
  - Limiting cycling to once-per-day, even if it would be advantageous to cycle more than once.
  - Dispatching myopically without regard to revenues in other markets.
- These issues are a problem with the *tool* itself not with underlying data, degrees of information, or the ability to forecast.

Basic optimization models generate more reasonable EAS revenue offsets

- MA AGO developed and ran a basic linear optimization model to simulate ESS dispatch and calculate EAS revenues.
  - Model maximizes energy and TMSR revenues (including FRM as applicable).
  - Model approximates the approaches laid out by the EMM in its ER20-308 [1] comments but relies on current CEA pricing data.
  - Model returns efficient dispatch schedules and EAS revenues that can be cleanly substituted into the CEA DCF model.
- Two methodologies:
  - Battery has perfect foresight of hourly RT LMP and TMSR price. (Analogous to EMM's Approach 1.)
  - Battery is optimally scheduled based on known DA LMP and expected TMSR prices but is run in real-time and earns RT LMP, TMSR. (Analogous to EMM's Approach 2.)
  - When FRM available, model constrains dispatch to ensure energy availability in on-peak hours.
- Model formulation in Appendix. AGO offers the model itself, model outputs, and a memorandum summarizing the model's formulation in the interest of transparency.

[1] EMM Comments at 6 https://elibrary.ferc.gov/eLibrary/filelist?accession_num=20191112-5337&optimized=false

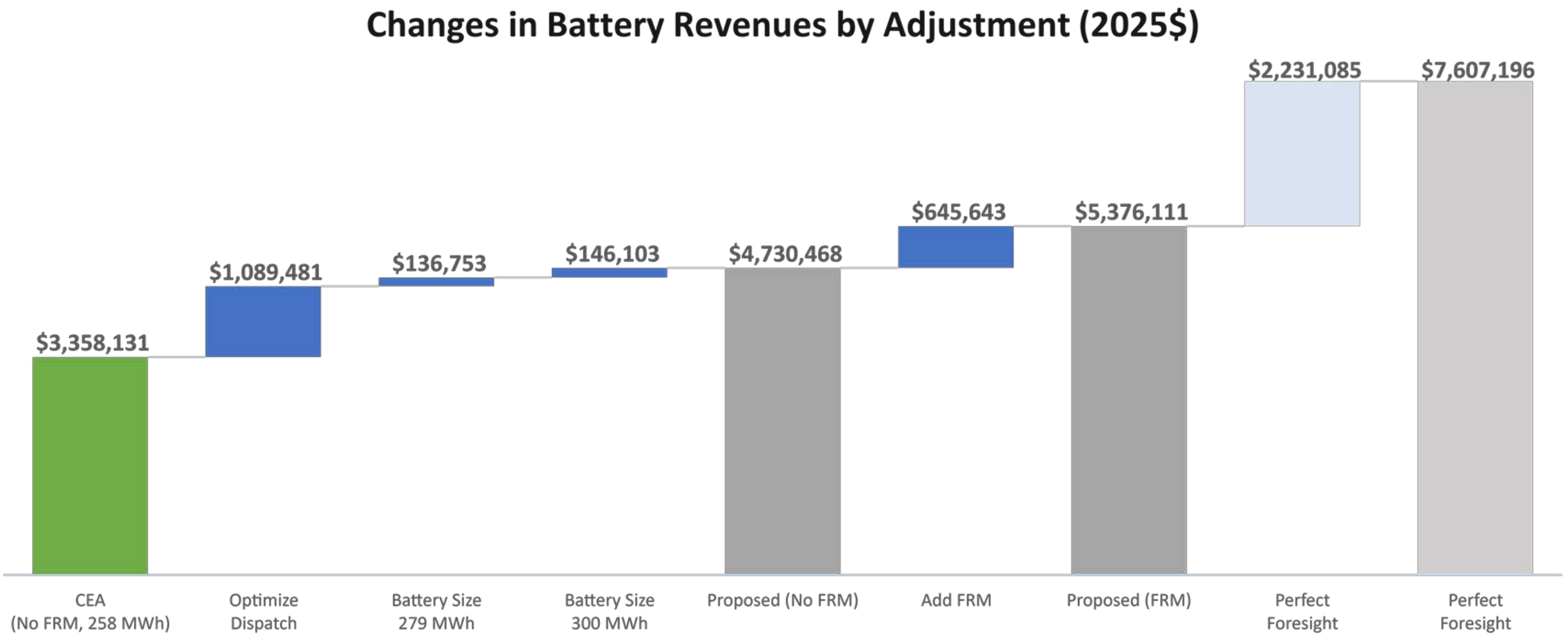
AGO results suggest a reasonable developer could earn $31-36/kW (vs. CEA's $22-32/kW)

Comparison of EAS Revenue Estimates for Energy & TMSR (2025$)

	Revenue per KW-ac		Change from CEA	
Source	**w FRM**	**No FRM**	**w FRM**	**No FRM**
CEA	$32.05	$22.39		
AGO				
Perfect Knowledge	$50.71	$50.46	58%	125%
DAM Knowledge	**$35.84**	**$31.54**	**12%**	**41%**
EMM*				
Perfect Knowledge	$56.00		75%	150%
DAM Knowledge	$30.00		-6%	34%
DAM + CTS	$34.00		6%	52%

** EMM values based on slightly different timeframe (Mar-2017 through Feb-2019) and do not adjust for scarcity. Adjusting for scarcity would reduce EMM estimates by about $1.5/kW.*

Improved dispatch increases EAS revenue by $1.1 million; size corrections add another $283k



AGO estimates, assuming DAM information, are a reasonable middle-ground for the EAS Offsets

- AGO Proposes Energy and TMSR EAS revenues of:
  - Assuming FRM Maintained: **$5,375,295 ($35.84/kW-year)**
  - Assuming FRM Sunset: **$4,730,619 ($31.54/kW-year)**
- Overall EAS revenue estimates should also include CEA's estimate of regulation revenues ($22.84/kW-year).
- AGO estimates, based on DAM outcomes, offer a reasonable middle-ground between CEA's very low values and revenues assuming perfect foresight.
  - AGO model doesn't require sophisticated intraday dispatch or complex forecasting. AGO estimates require known DAM energy price curves and a generic assumption of expected TMSR prices.
  - AGO approach, and results, comport with EMM's expectations of earnings available to a "reasonably competent" storage operator.
- More advanced dispatch schemes could yield revenues in excess of the AGO proposed values.
  - There is significant headroom between perfect dispatch and the AGO proposed value.
  - Participation in other markets (e.g. regulation) could generate more EAS revenue.

Appendix

LP Formulation

$max \sum_{t=0}^{T} (Q_{EA,t} \times P_{LMP,t} + Q_{TMSR,t} \times P_{TMSR,t})$	Maximize revenues from energy and TMSR. **Q** is rated as MWh-ac
$0 \leq \mathrm{I_t} \leq \mathrm{ESS_{Charge\ Rate}}$	Limits Battery Injections
$0 \leq \mathrm{W_t} \leq \mathrm{ESS_{Discharge\ Rate}}$	Limits Battery Withdrawals
$\sum_{\mathrm{t=0}}^{\mathrm{T}} (\mathrm{I_t}) \leq \mathrm{Total\ Injection\ Limit}$	Limits total cycling to an average of one-per-day
$0 \leq SOC_t \leq SOC_{max}$	Limits quantity of stored energy.
$SOC_t = SOC_{t-1} + I_{t-1} - W_{t-1}$	Keeps track of energy across time.
$Q_{EA,t} = \eta W_t - \frac{I_t}{\eta}$	Calculates ac-rated output based on charging and discharging in each period.
$0 \leq Q_{TMSR,t} \leq \eta SOC_t$	Constrains TMSR sales to available energy
$Q_{TMSR,t} \leq \eta W_t - Q_{EA,t}$	Further constrains TMSR to avoid double-counting with energy arbitrage sales.
$If \quad (FRM\ Hour_t = OnPeak)\ and\ (FRM\ Threshold_t < P_{LMP,t})$ $Then \quad Q_{TMSR,t} = 150$	Sets quantity of TMSR to 150 MWh in on-peak hours.

Battery Specification & Operating Parameters

Parameter	Units	Value	Notes
Capacity	MW-ac	150	Same as CEA, Measured at the Revenue Meter
Stored Energy	MWh-ac	300	Measured at the Revenue Meter (CEA assumes 258 MWh deliverable)
Round-trip Efficiency	%	86%	Same as CEA
One-way Efficiency	%	92%	Assumed Symmetric; $92\% = \sqrt{86\%}$
TMSR Capacity	MW-ac	150	Same as CEA
Total Study Injection Limit	GWh-ac	3.285	Same as CEA; = 365 Days x 3 Years x 300 MWh-ac