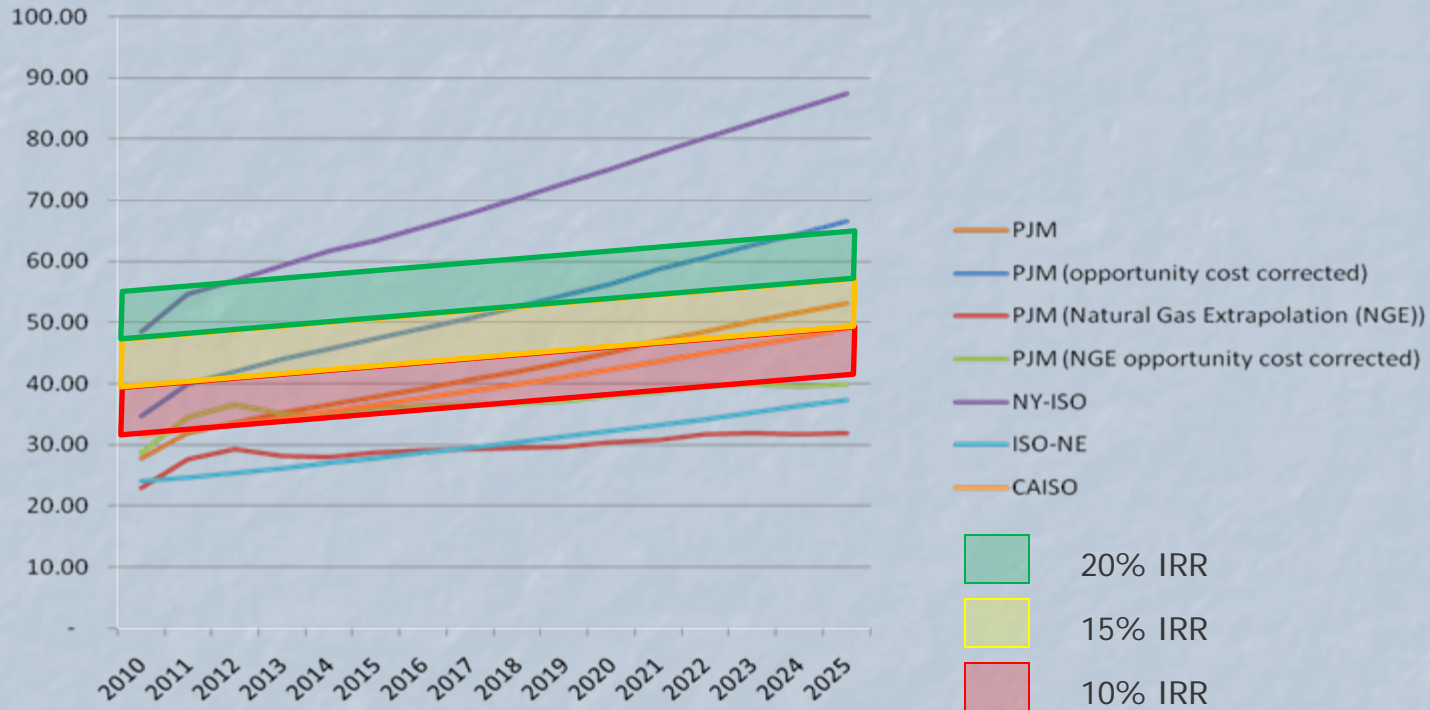


# Large-Scale Energy Storage Technology Overviews

UltraBattery – Grid Storage.  
Advanced Lead – Carbon  
Technology

# Regulation Income Projection (Estimated Service Business 15 Yr IRR)\*

\* UltraBattery Storage Solution



- Optimisation will move IRR bands downward
- Bidding strategy will also move IRR bands downward

# Grid Scale Energy Storage

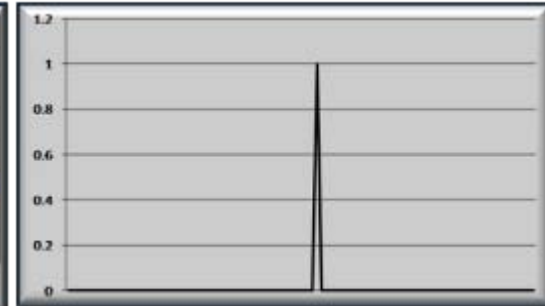
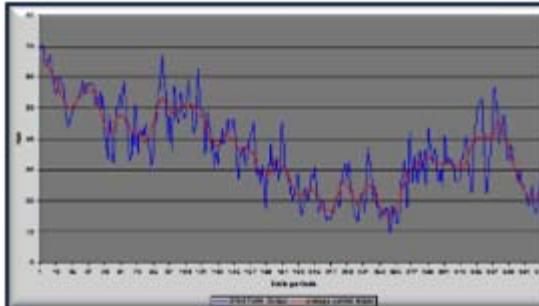
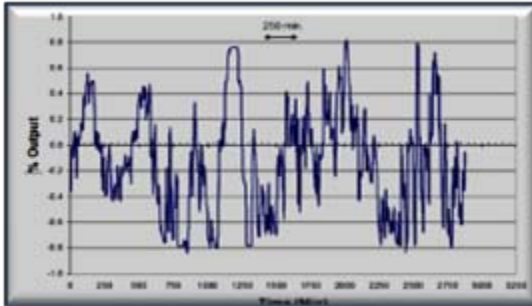
Grid Stability



Renewable Smoothing



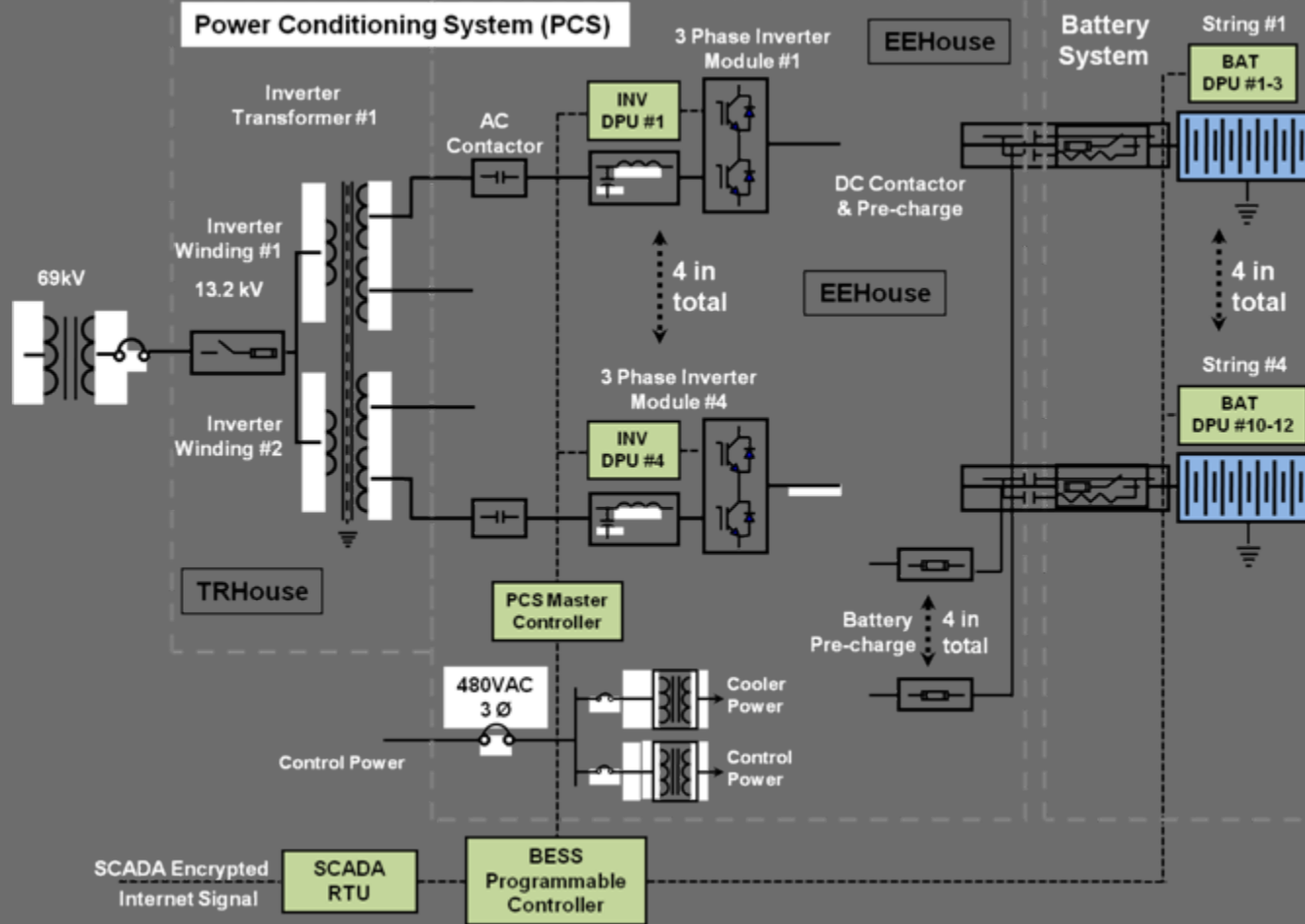
Data Center UPS



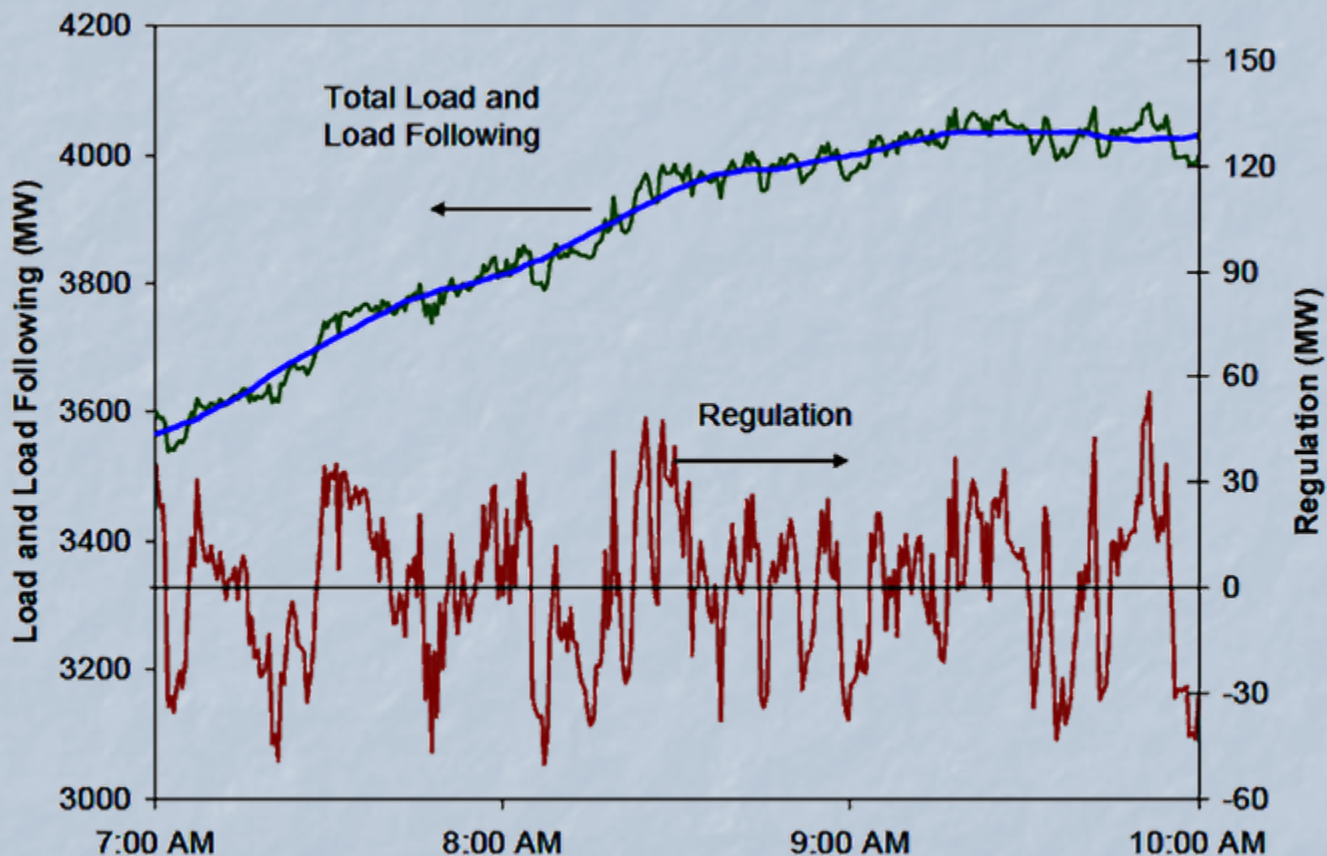
# Reliable Grid Scale Storage



# Power Conditioning System

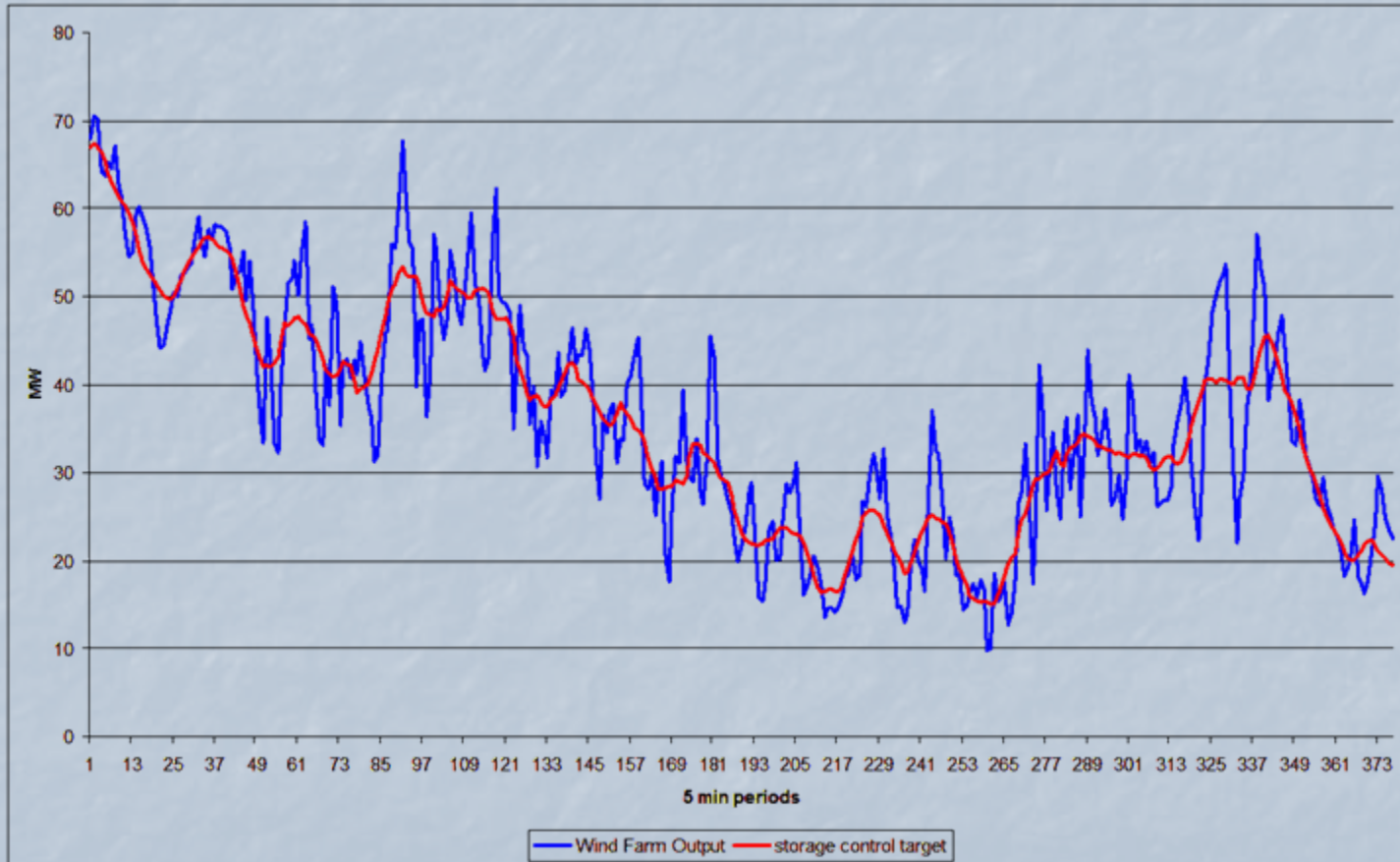


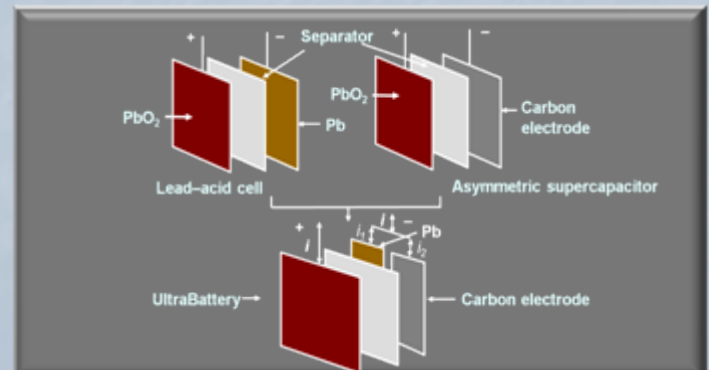
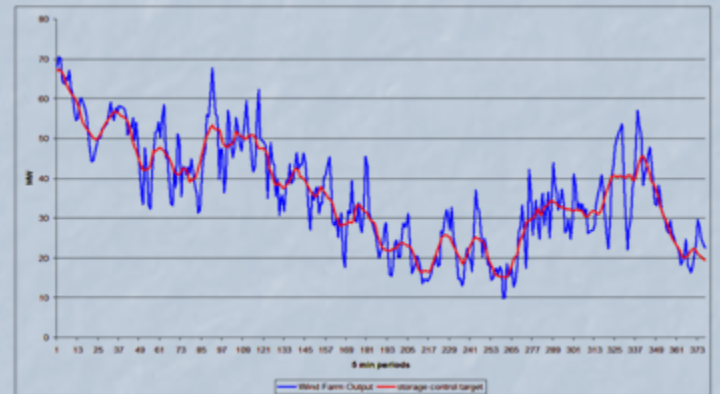
# Regulation



\* PJM

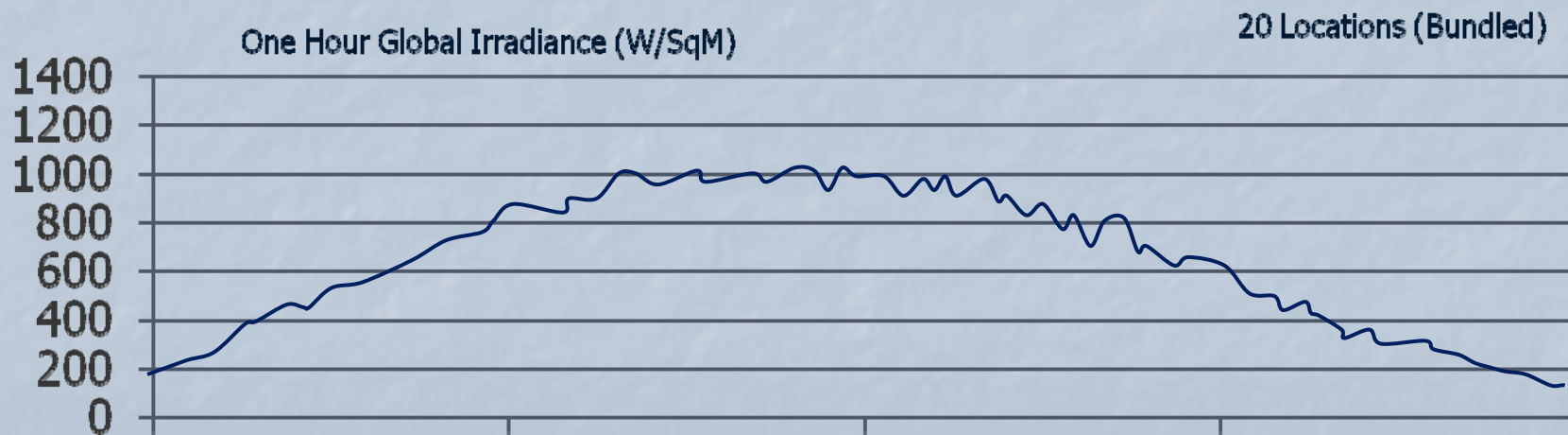
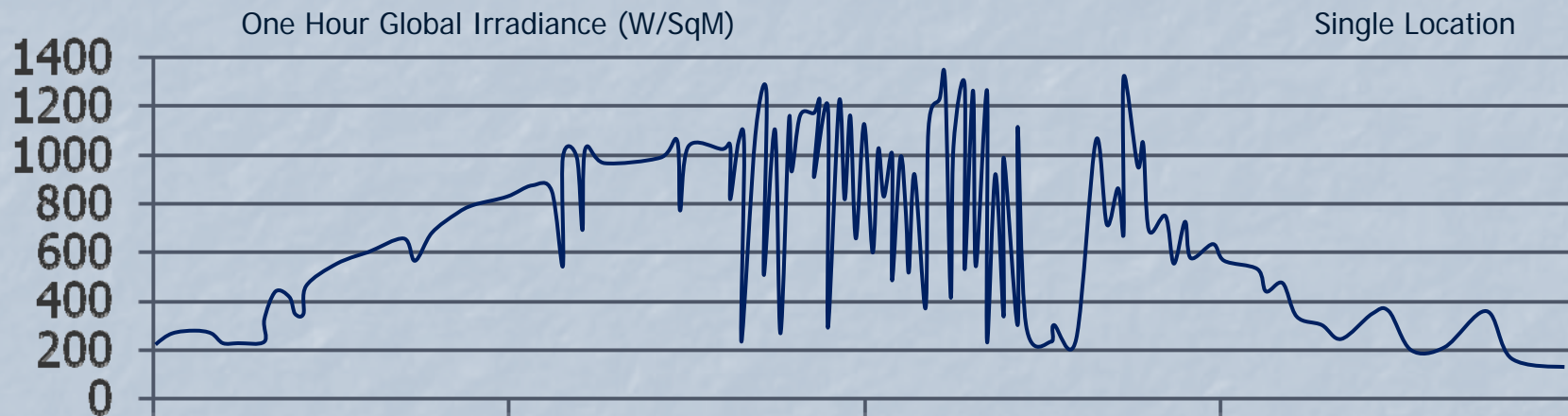
# Wind Energy Ramp Rate





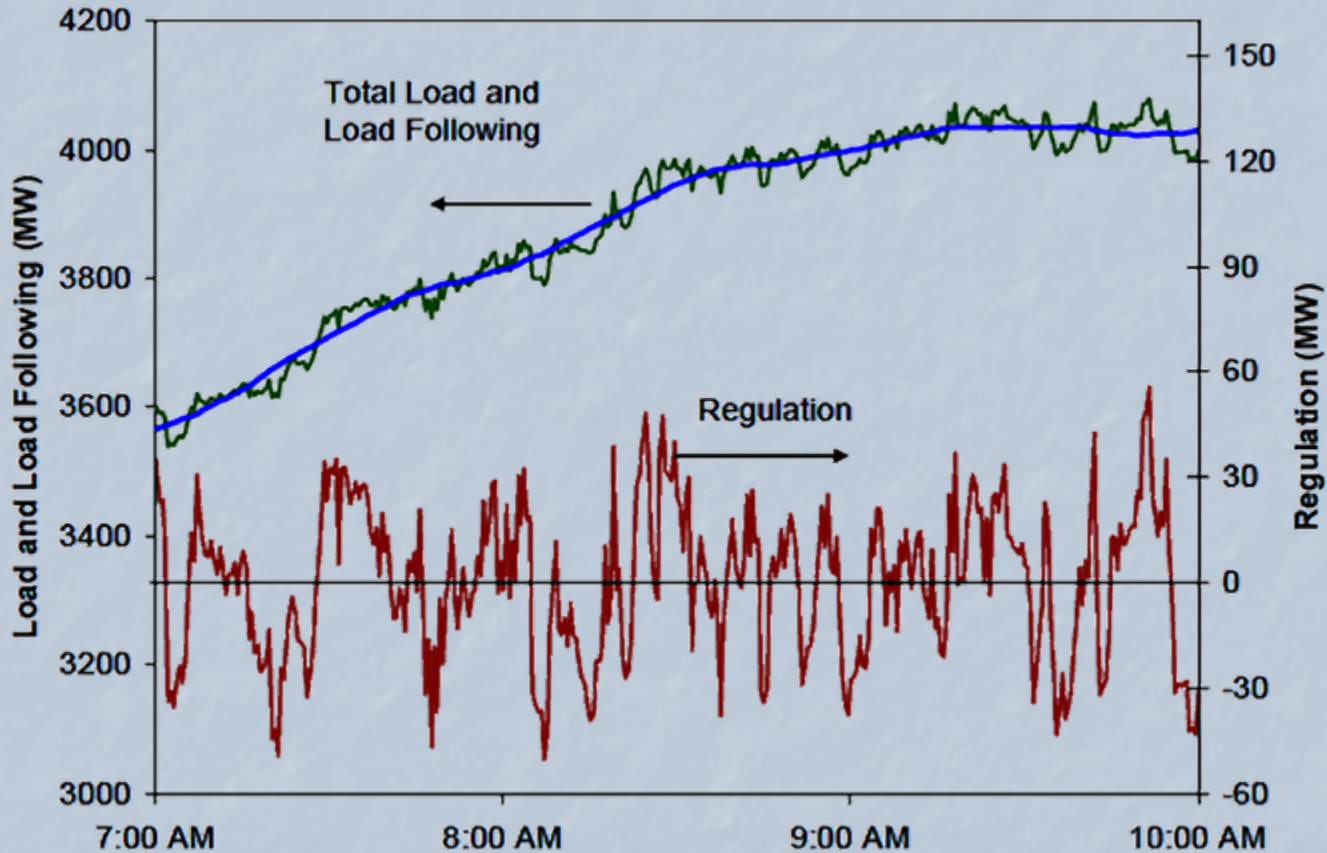


# Solar Energy Smoothing



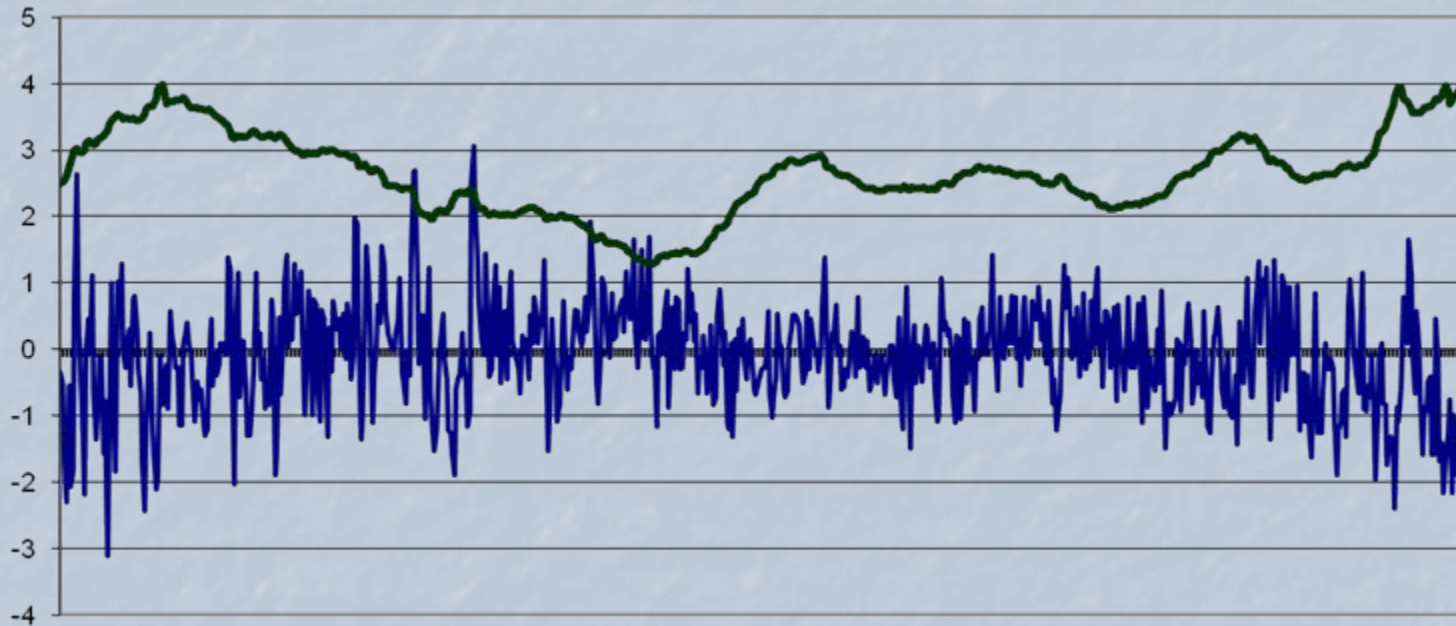
\* Adapted from Perez 2006

# Regulation using Storage

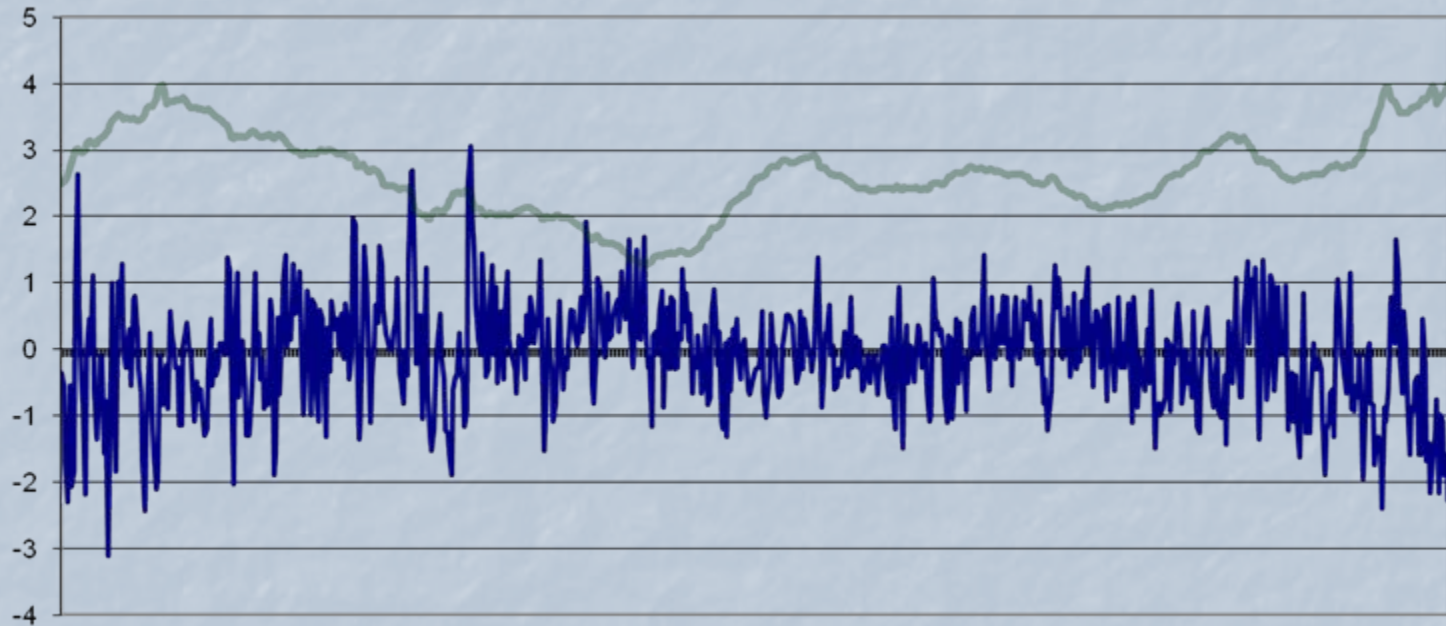


\* PJM

# Regulation Signal and Storage SoC

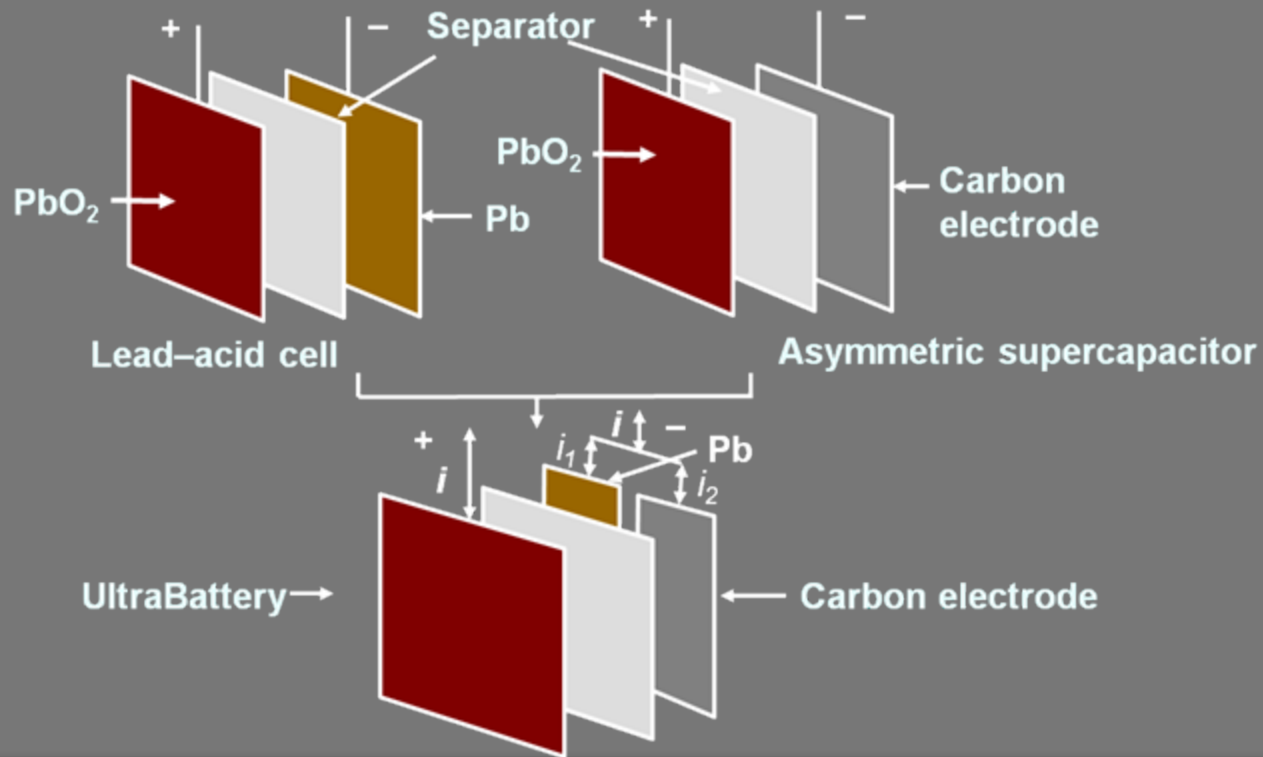


# Power Impact on Storage



# UltraBattery

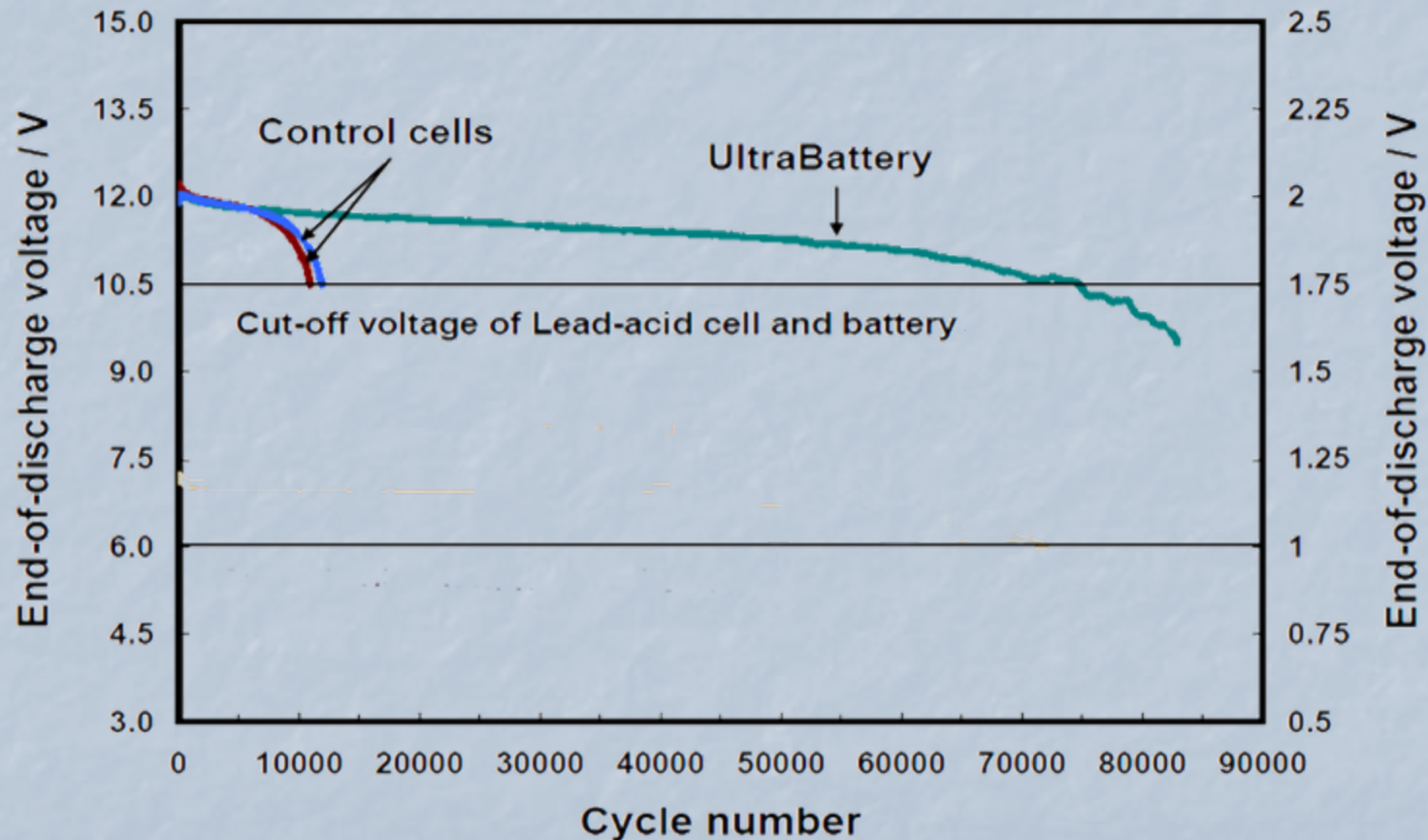
UltraBattery is a hybrid energy-storage device, which combines an asymmetric supercapacitor and a lead-acid battery in one unit cell, without extra electronic control.



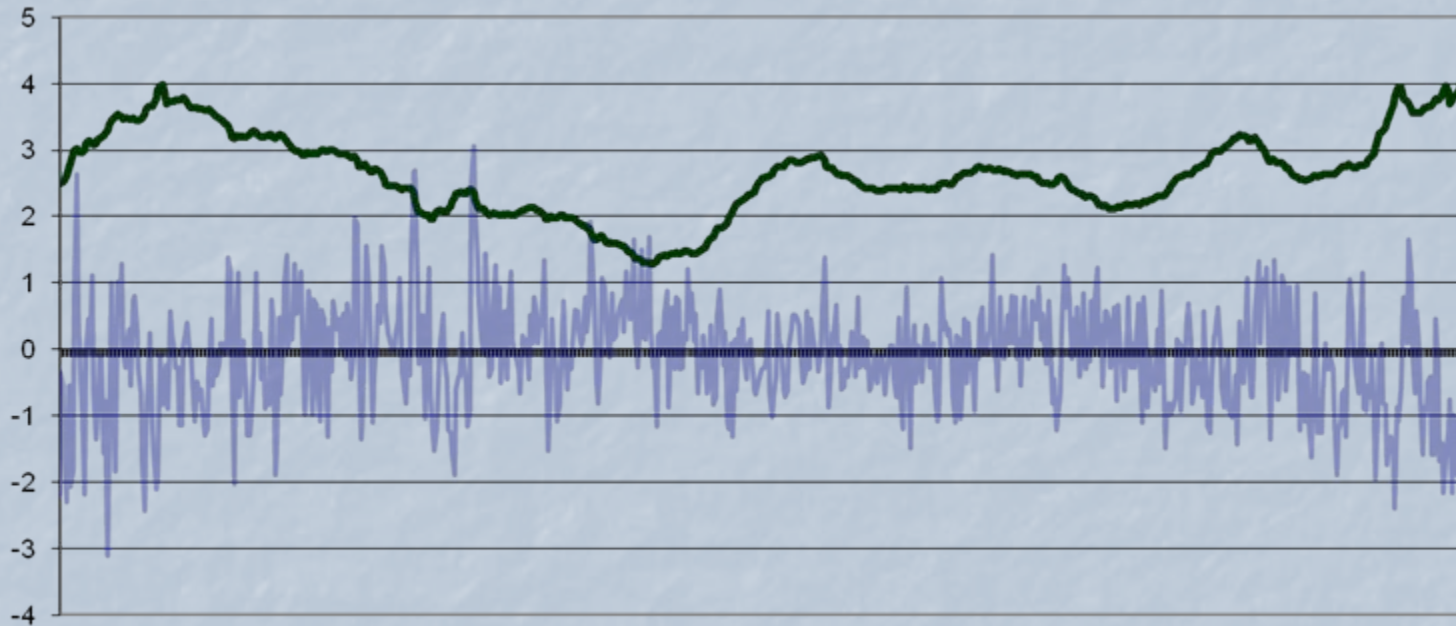
# An "Order of Magnitude" Breakthrough

- Lead Acid is the leading technology in terms of power \$/kW. Challenge has been longevity.
  - *"Using the HRPSoC cycling profile at the 1C1 to 4C1 rate, the UltraBattery cycle performance was about **thirteen times**\* greater (>15,000 cycles) than the AGM VRLA battery (1,100 cycles)".*
- \*Results of independent Sandia testing released December 2008*

# Designing for Power Impact

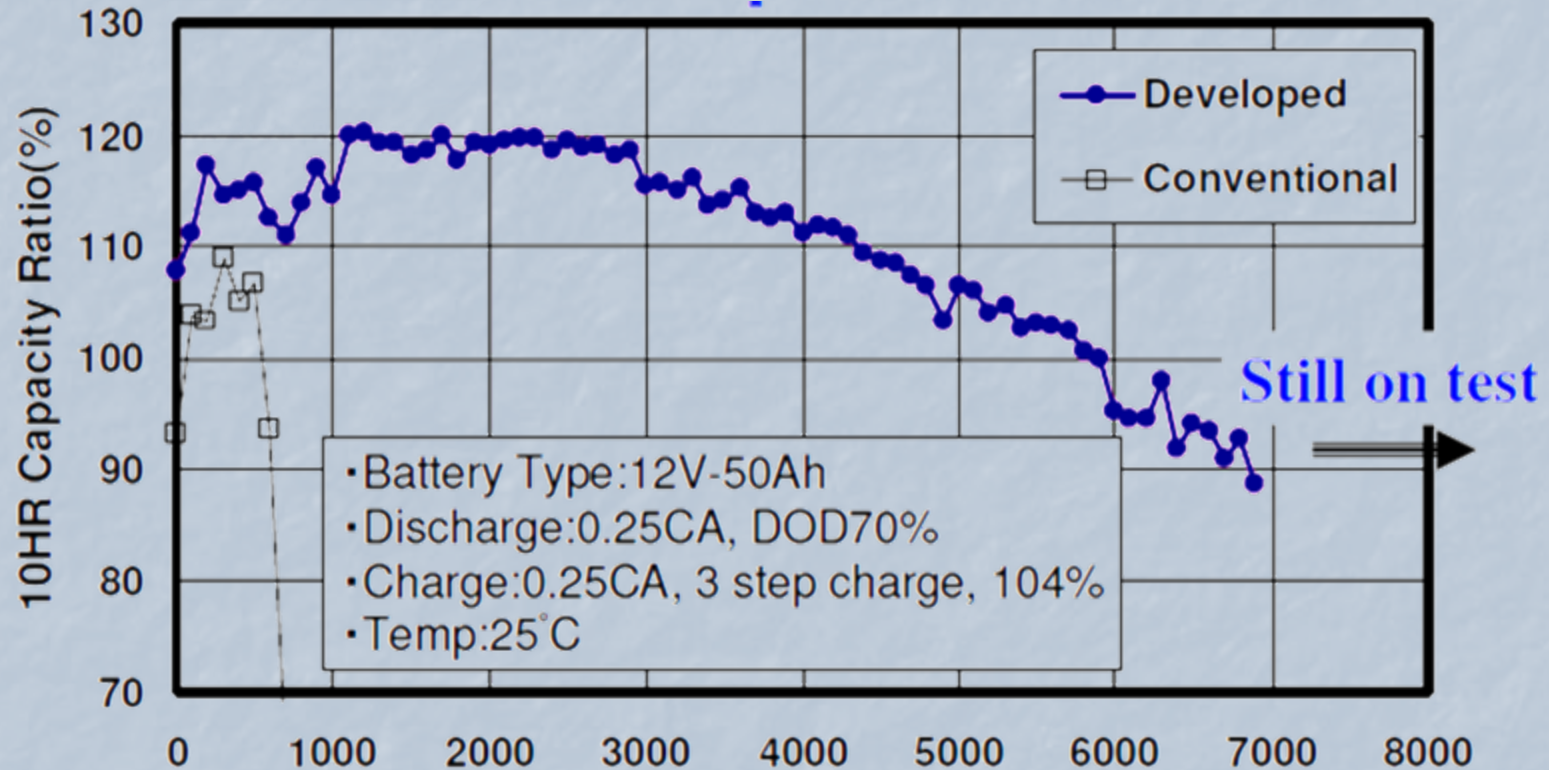


# Energy Impact on Storage





# Designing for Energy Impact



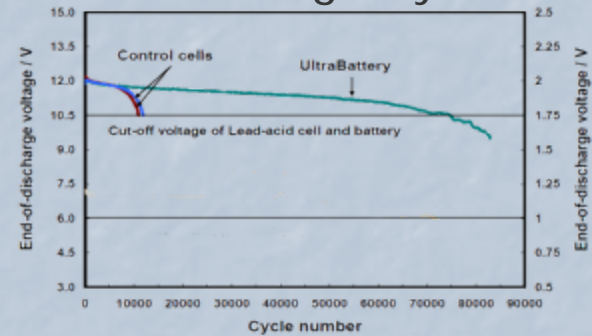
\* Furukawa test results of optimised VRLA presented in Macau ALABC 2009

# Reliable Storage for Grid Stability

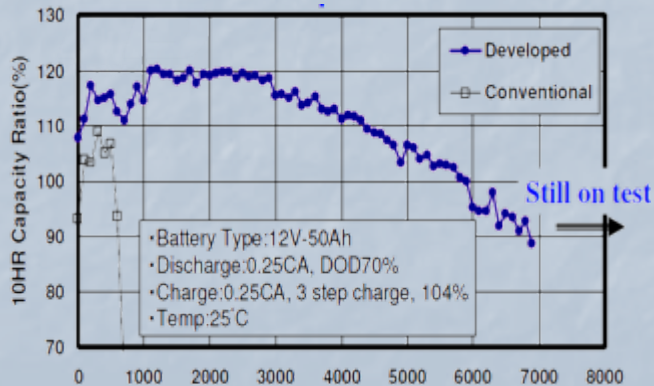
## Reliable Low Cost Storage



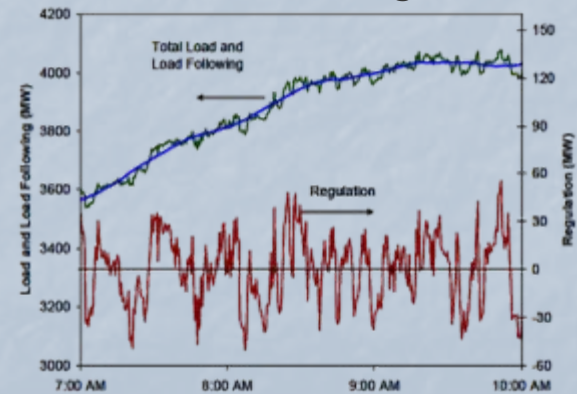
## Power Longevity



## Energy Longevity



## Continuous Regulation



# Economic Objective

## Objective

- Achieve ability to perform continuous regulation.
  - BESS suitable for 15 year operation with one battery replacement cycle.
  - Total Service cost target of  $\sim \$25$  / MW of regulation / hr

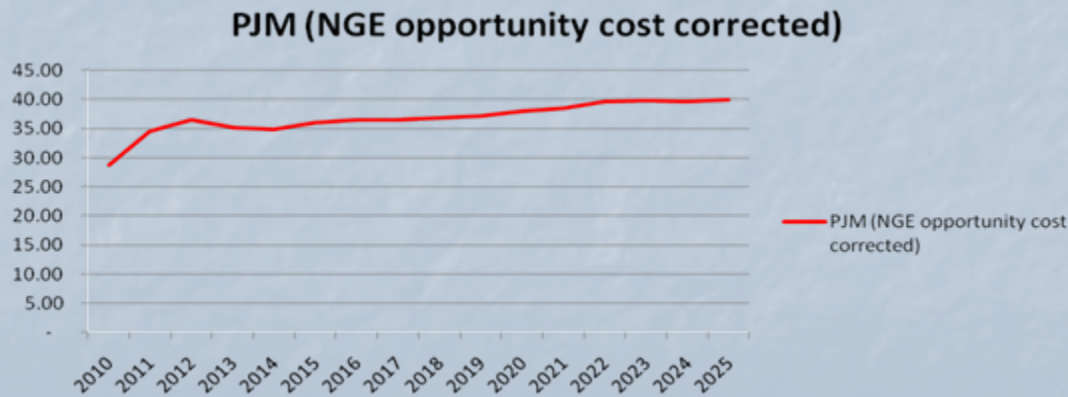
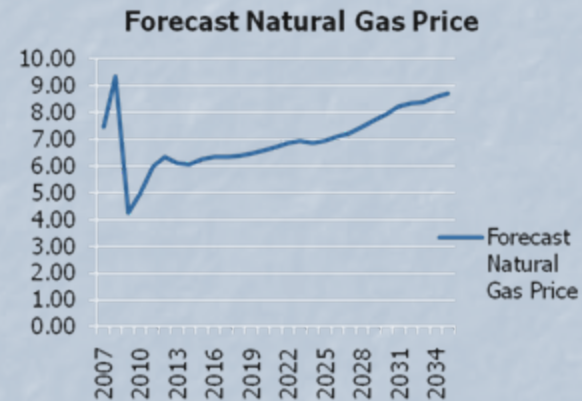
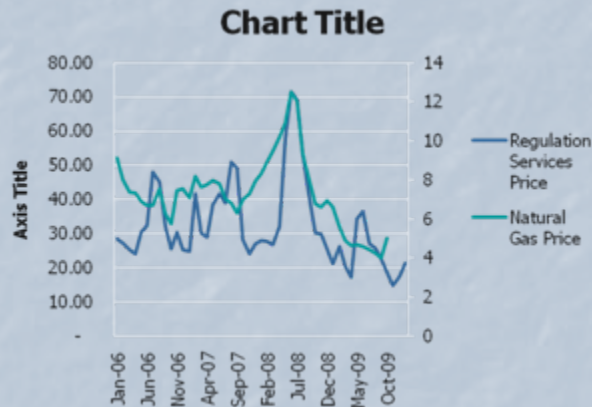
## Stretch Objective

- Optimize solution and achieve 10-15 years continuous operation without battery replacement.
  - Service cost target of  $\sim \$20$  / MW of regulation provided / hr

# Regulation Income Projection

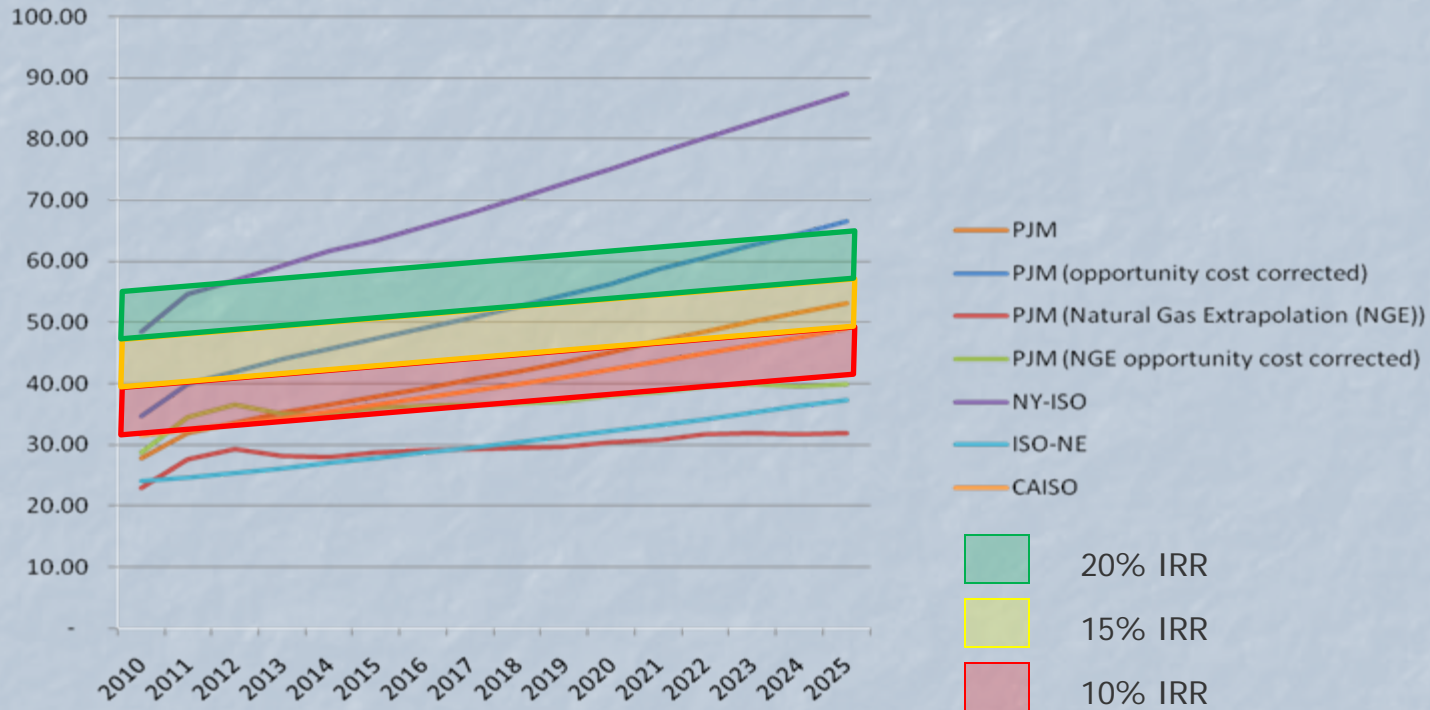
	2010	2011	2012	2013	2014	2015	2020	2025
<b>Frequency Regulation Price (\$/MWh)</b>								
PJM	27.73	31.99	33.63	35.17	36.62	37.93	45.05	53.21
PJM (opportunity cost corrected)	34.66	39.98	42.03	43.97	45.77	47.42	56.32	66.51
PJM (Natural Gas Extrapolation (NGE))	22.95	27.56	29.21	28.12	27.94	28.78	30.39	31.97
PJM (NGE opportunity cost corrected)	28.68	34.45	36.52	35.16	34.92	35.97	37.99	39.97
NY-ISO	48.50	54.57	56.92	59.25	61.67	63.40	75.14	87.47
ISO-NE	24.00	24.72	25.46	26.23	27.01	27.82	32.25	37.39
CAISO	31.50	32.45	33.42	34.42	35.45	36.52	42.33	49.08
<b>Average frequency regulation price</b>	<b>33.47</b>	<b>37.23</b>	<b>38.87</b>	<b>39.80</b>	<b>40.97</b>	<b>42.22</b>	<b>48.81</b>	<b>56.08</b>

# Regulation Income Projection (Natural Gas Analysis applied to PJM)



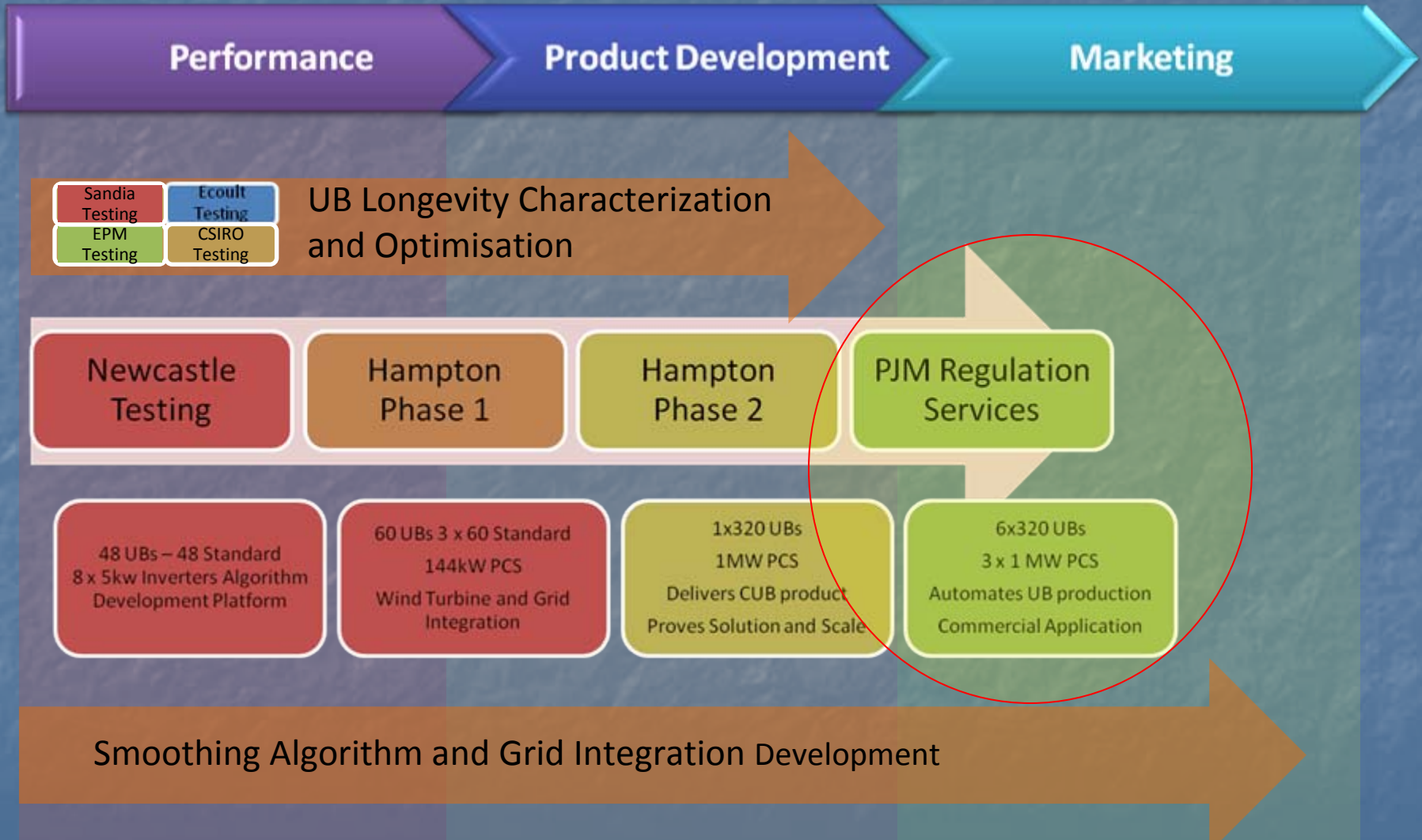
# Regulation Income Projection (Estimated Service Business 15 Yr IRR)\*

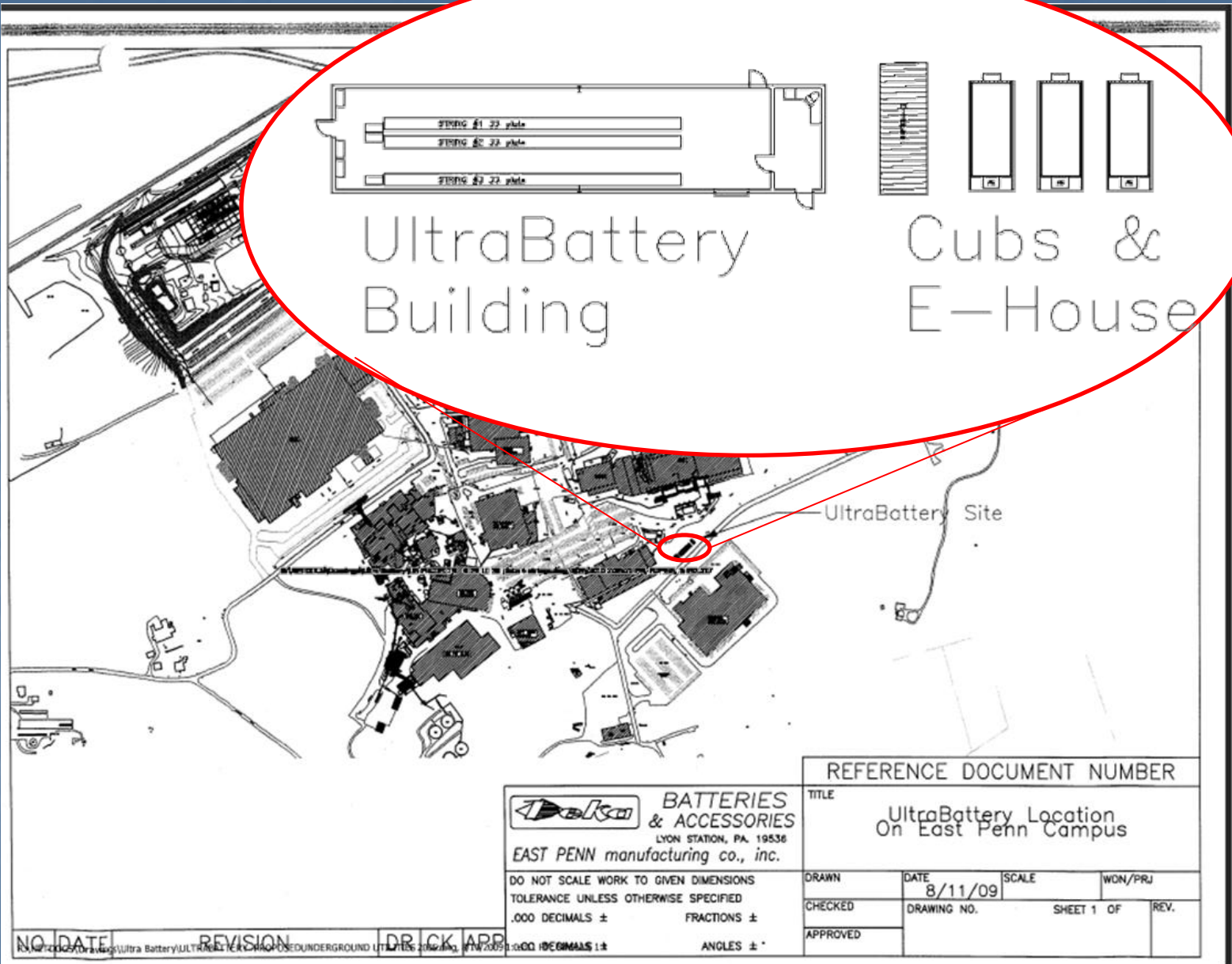
\* UltraBattery Storage Solution



- Optimisation will move IRR bands downward
- Bidding strategy will also move IRR bands downward

# UltraBattery applied to Grid Ancillary Services





UltraBattery Building

Cubs & E-House

UltraBattery Site

REFERENCE DOCUMENT NUMBER

**Dakota** BATTERIES & ACCESSORIES  
 LYON STATION, PA. 19536  
 EAST PENN manufacturing co., inc.

TITLE  
 UltraBattery Location  
 On East Penn Campus

DO NOT SCALE WORK TO GIVEN DIMENSIONS  
 TOLERANCE UNLESS OTHERWISE SPECIFIED  
 .000 DECIMALS ±      FRACTIONS ±  
 ANGLES ± °

DRAWN	DATE 8/11/09	SCALE	WON/PRJ
CHECKED	DRAWING NO.	SHEET 1 OF	REV.
APPROVED			

NO.	DATE	REVISION	DR.	CHK.	APP.
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