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Electric Energy Storage Technology Options for the Electric Enterprise

Linking Supply with Changing Demand

Institute for Regulatory Policy Studies, Illinois State University

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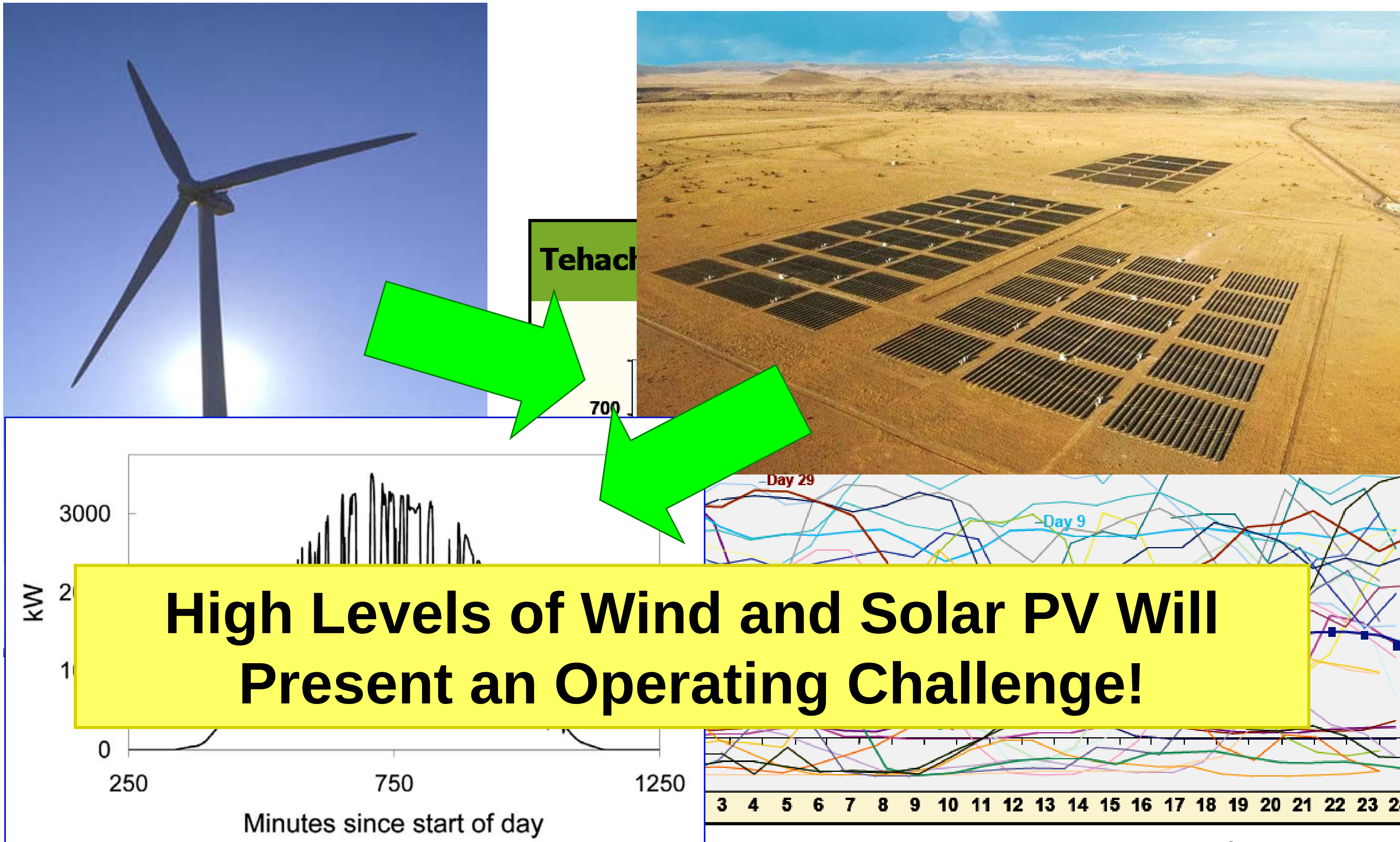
Agenda

- Industry Drivers for Energy Storage Solutions
- Overview of Energy Storage Options
- Applications for Energy Storage
- Value of Energy Storage by Application
  - Cost and Benefit Analysis
  - Life Cycle Cost Analysis
  - Grid Integration Activities
- Summary and EPRI Perspectives

Industry Drivers for Energy Storage Solutions
Operating Challenges: Variability & Uncertainty

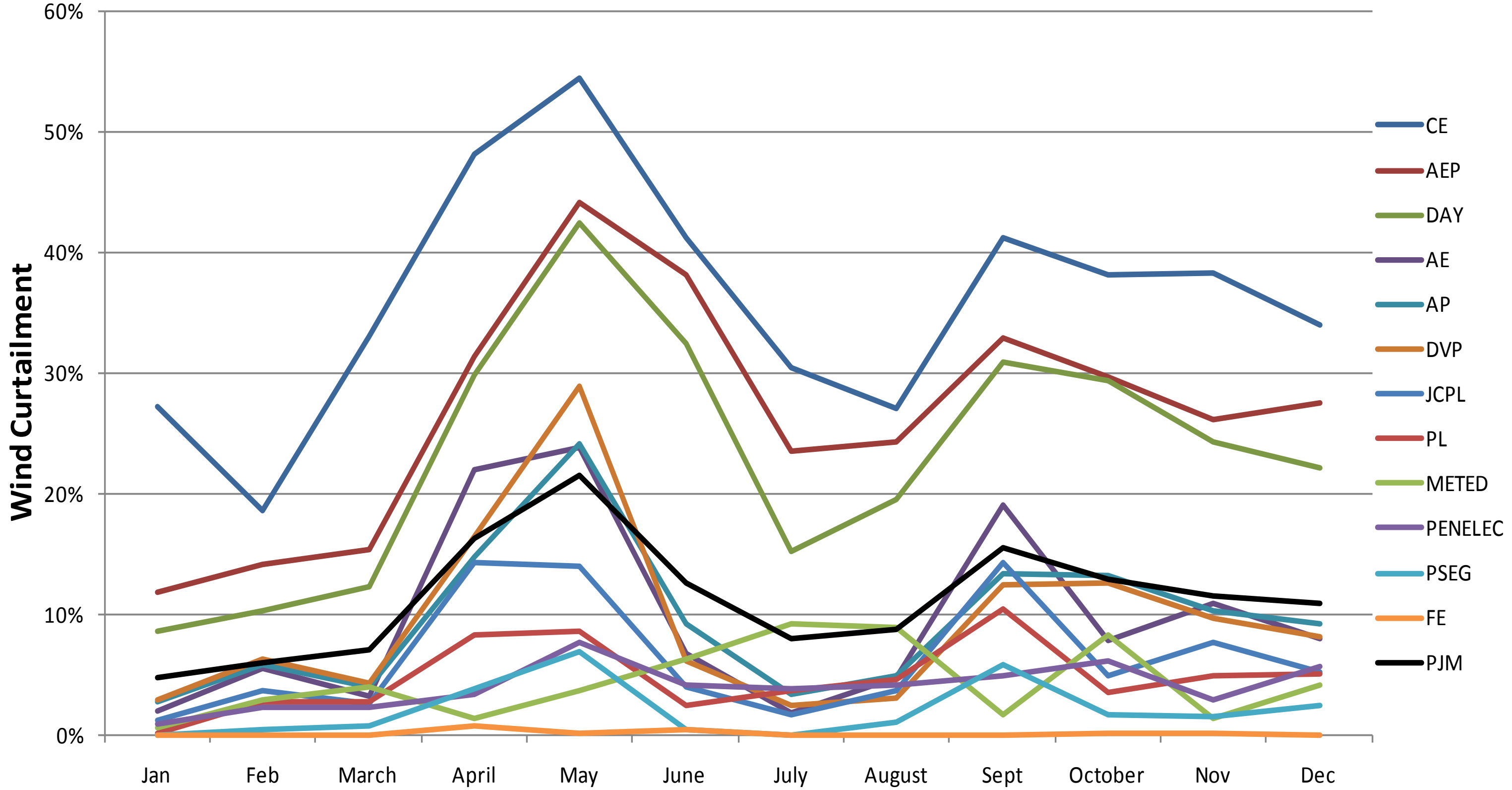


High Levels of Wind and Solar PV Will Present an Operating Challenge!

PJM Wind Curtailment (2015)

Wind meets 5% of Demand; ~ $ 700 M System Wide Congestion Cost

Considerable wind curtailment occurs in COMED and AEP control areas due to transmission thermal and contingency overloads.



Source: EPRI Study Underway in 2010

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Industry Driver: Grid Infrastructure Investments for Delivery and Reliability

- Cost of Power Disturbances to the US Economy $ 180 B/year
- Cost of a massive blackout ~ $ 10 B / event
- CapEx in Transmission Investments ~ $ 10 B / 2011
- CapEx in Distribution Investments ~ $ 20 B /yr 2010 growing to $ 35 B /yr by 2030
- By 2030, the electric utility industry will need to make a total infrastructure investment of $1.5trillion to $2.0 trillion. (+ $15.5 B with Renewable Penetration)

What if we could Store and Deliver Electricity "when and where" it was needed?

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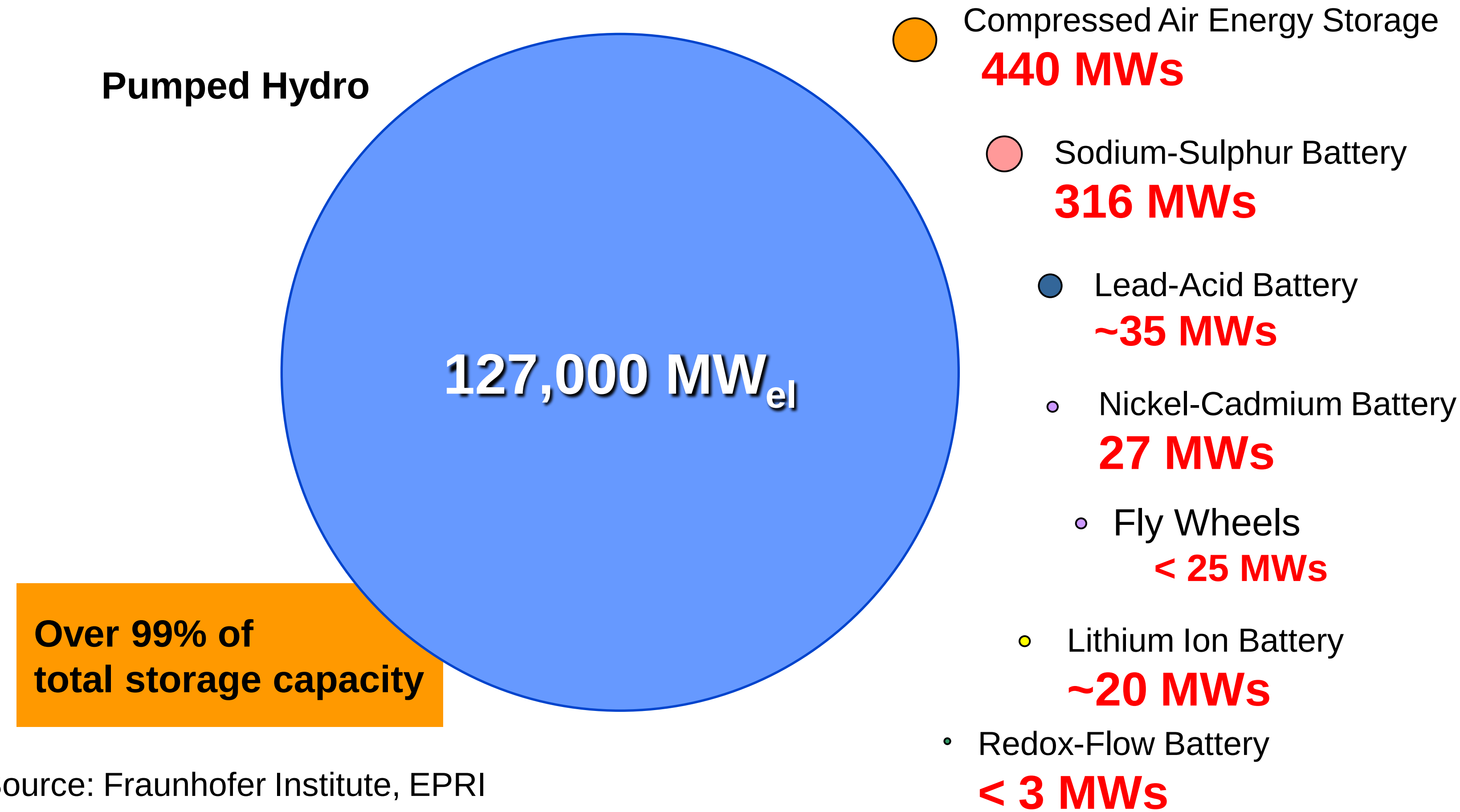
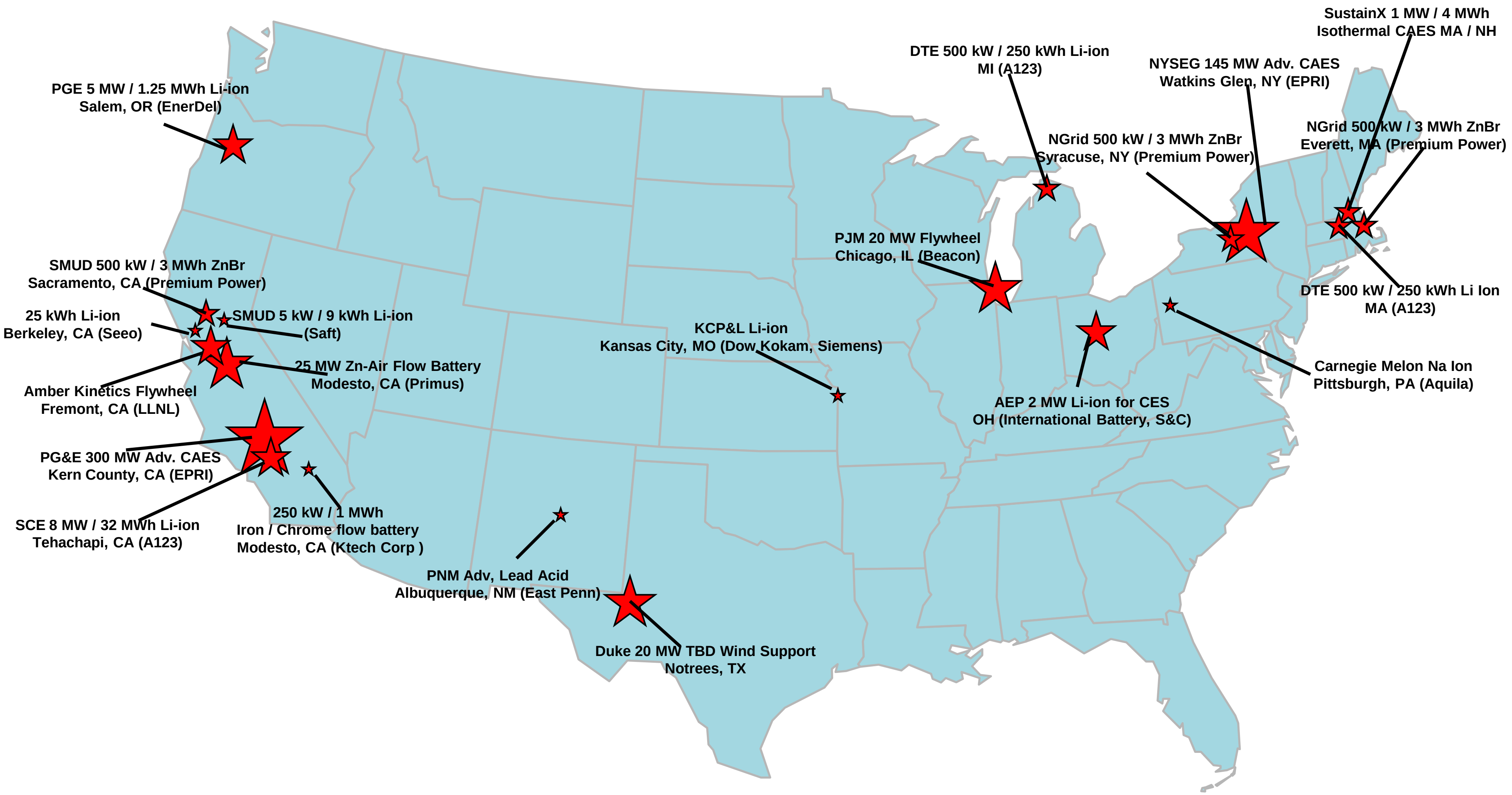
Today, Energy Storage Penetration is Very Small

Worldwide installed storage capacity for electrical energy



Source: Fraunhofer Institute, EPRI

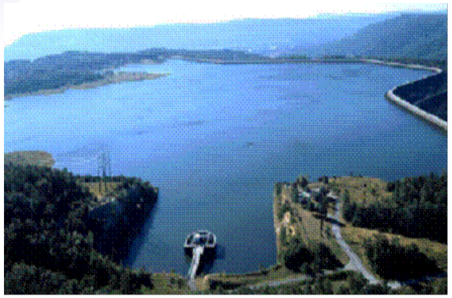
Energy Storage Grid Integration Activities



ARRA Funded Energy Storage Demonstrations in the U.S.

Overview of Energy Storage Solutions

Bulk to Distributed Storage Solutions in the Smart Grid









MWs to kWs: seconds, min, hours of energy duration

Energy Storage Options

Note: Today's Costs; Site Specific Application Cost can Vary

Storage Option	Application	Level of Maturity	Energy Duration hrs (cycles)	Efficiency ac/ac %	Total Installed Capital Cost $ / kW	Total Installed Cost $/kW-h
Pumped Hydro	ISO Services Wind Integration	Mature	10-20 (>13000)	76-85	$1900-$3800	310-380
Compressed Air	ISO services Wind Integration	Demo	10-20 (>13000)	4000 Btu/kWh 0.7 ER	$810-$1020	81-102
NAS	Grid Support Wind Integration	Mature	6 (4500)	80	$3900-$4190	650-700
Lead Acid Battery Adv. Lead Acid Battery	Grid Support ISO Services Wind / PV	Mature Demo	4 (2200-4500)	85-90	$2020-$3040	505-760
Flow Battery (Various Types)	Grid Support Wind / PV Integration	Demo	4 (>10000)	60-70	2350-4500	470-1125
Li-ion Battery	Grid Support C&I Energy Mgt ISO Services PV Integration	Demo	0.25 (>10000) 2 (5000)	90	1500-1800 2100-4650	6000-7200 1050-1550
Fly Wheels	ISO Services	Demo	0.25 (>>20,000)	90	1900-2250	7800-7900

Compressed Air Energy Storage

Alabama Electric Cooperative's CAES Plant (110 MW-26 Hr)

NaS Battery at Xcel – Luverne, MN

- 1.25 MVA / 1.0 MW – Outdoor Installation
- Wind smoothing
- Dispatched wind
- Peak shaving
- Energy arbitrage

Advanced Lead Acid Battery

Shown below is Xtreme Power 1.5 MW / 1 MWh

Applied in Wind PPA and PV Smoothing Applications

Flow Battery Systems
Decouple Power &Energy / Positioned for >5 hrs storage

Zn / Br Systems

- 0.5 MW / 2.8 MWh Prototype

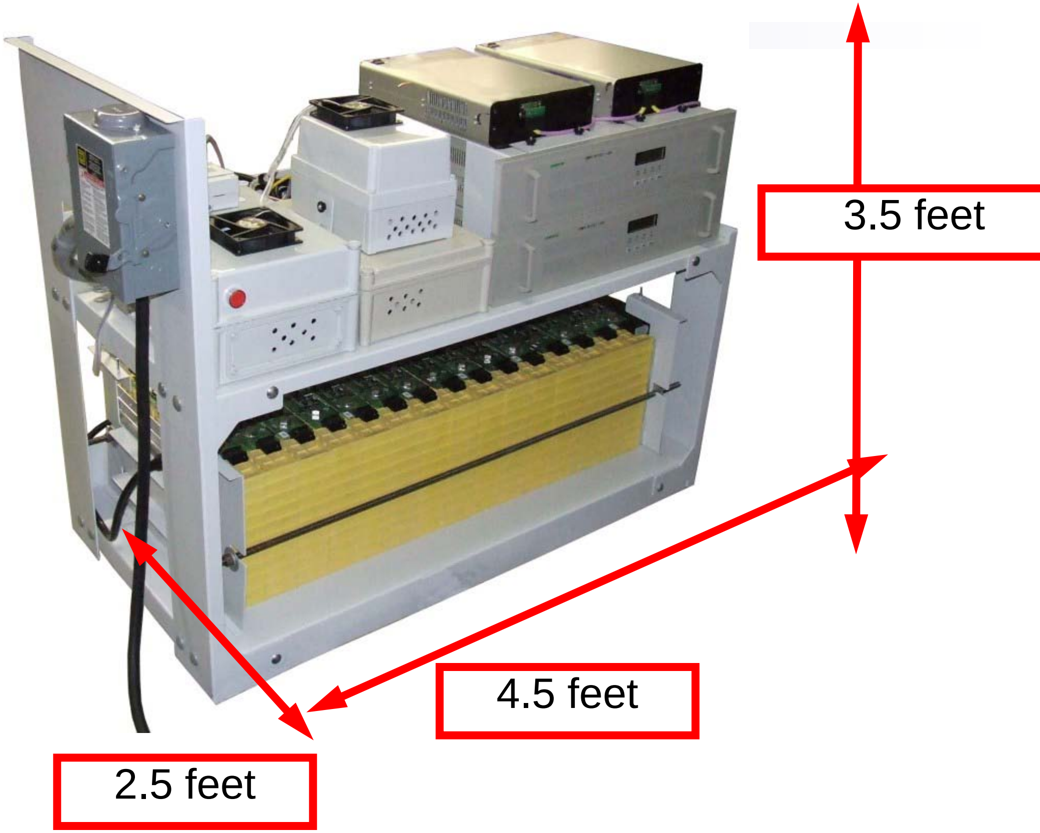
Others include:

- Vanadium Redox
- Fe / Cr
- Zn / Cl
- Zn / Air

20-MW/15-min Beacon Power flywheel in an ISO ancillary service application

AES 12 MW Li-ion System in Chile
Spin Reserve; Freq Reg

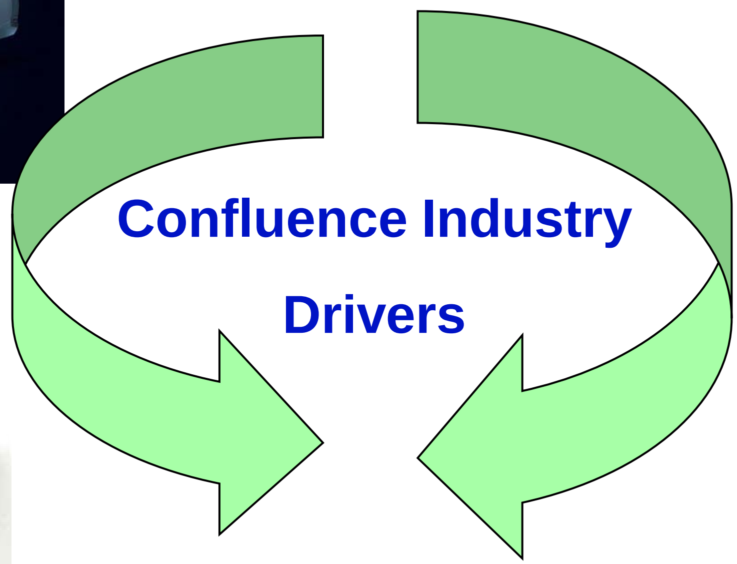
Li-ion Systems Emerging for Distributed Energy Storage (Utility and Customer side of meter)



6 kW / 20 kWh

Global Li-ion Production Capacity will be at a Scale to Enable Utility Grid Applications
~ 35 GWhs Production by 2015

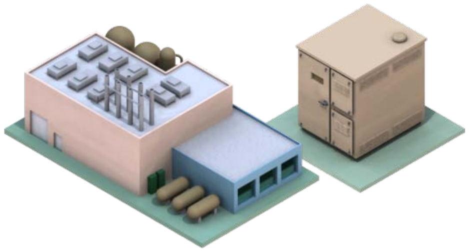


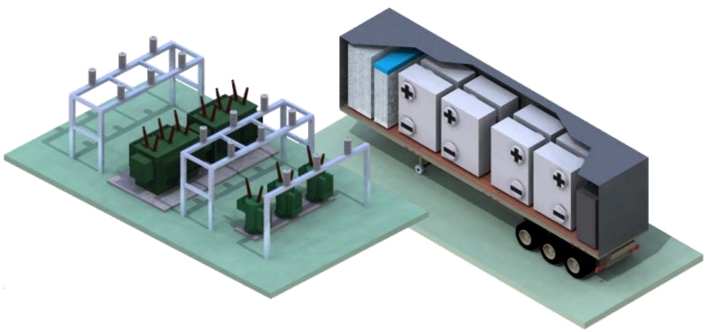

Use of a Common Storage Platform

Example High Value Application Products Using Li-ion Battery Technology

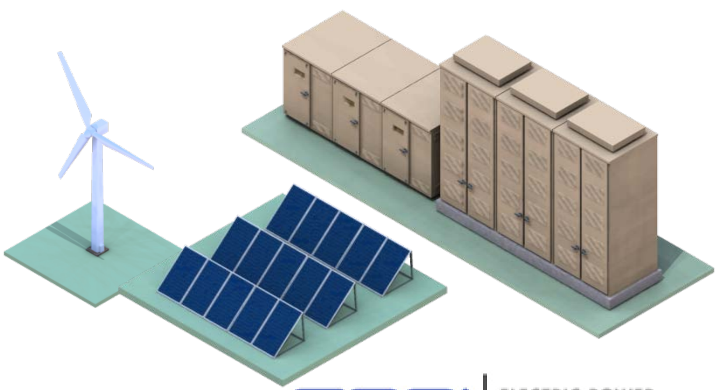
- **Utility DESS (25kW, 2-3hr)**
  - Peak shaving, load leveling
  - Local reliability
  - RTO market participation (with aggregation)



- **Grid Support (1MW, 2-3hr)**
  - Peak shaving, load leveling
  - T&D asset deferral / mgmt
  - RTO market participation



- **PV Integration (1MW, 30min)**
  - PV voltage & VAR support
  - PV time shifting (for cloud effects)
  - RTO market participation



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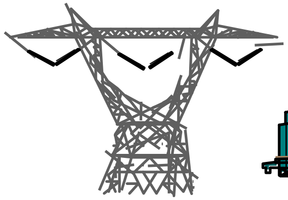
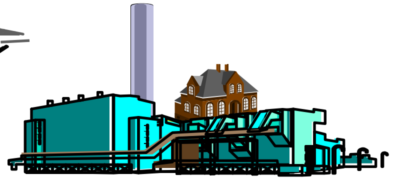
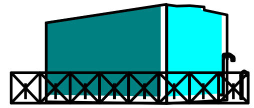
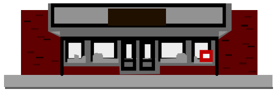
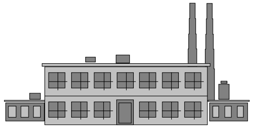
EPRI identified 10 key applications along the entire electric value chain … <u>the list is not comprehensive</u>

Whole Sale Energy Services Renewable Integration	Stationary T&D Support Transportable T&D Support Distributed Storage	C&I Energy Mgt C&I PQ and Rel. ESCO Aggregated	Home Energy Mgt Home Back-up



ISO System Level | Utility Grid Support | Customer Energy Mgt

Energy Storage Systems must be able to realize multiple operational uses across the energy value chain. There are some exceptions e.g. certain Ancillary Services

Higher Value for Energy Storage ($/kWh)

Higher Value for Discharge Capacity ($/kW)

Benefit Type

Time

End User

Distribution

Transmission

Utility System

ISO

Energy ($/kWh)

Reliability ($/kW)

Power ($/kW)

Operations ($/kVAR & $/kW)

Hours

Minutes

Seconds

Energy Management

T&D Investment Deferral

Renewable Integration

Energy Arbitrage

System Capacity

Reliability

Renewable Smoothing

Ancillary Services

Power Quality

DESS

T&D System Support

10s kW

100s kW

10s MW

100s MW

Size of Application

Business Case Analysis of Applications

Benefit Analysis: Total Recovery Cost Method

Sum of Value Streams: Capacity, CapEx Deferral, Regulation, etc…

Calculate Present Value of Value Streams (PV)

10% Discount Rate

Present Value of Benefits = Proxy for Total Installed Cost which can be justified for rate base

Value = Present Value of Benefits / kWh delivered from storage asset expressed as $/kWh ($ / kW-h)

Life Cycle Analysis: Cost per kWh Delivered

Capital Cost; Discount Rate

Efficiency (ac / ac)

Cost of off-peak power

O&M

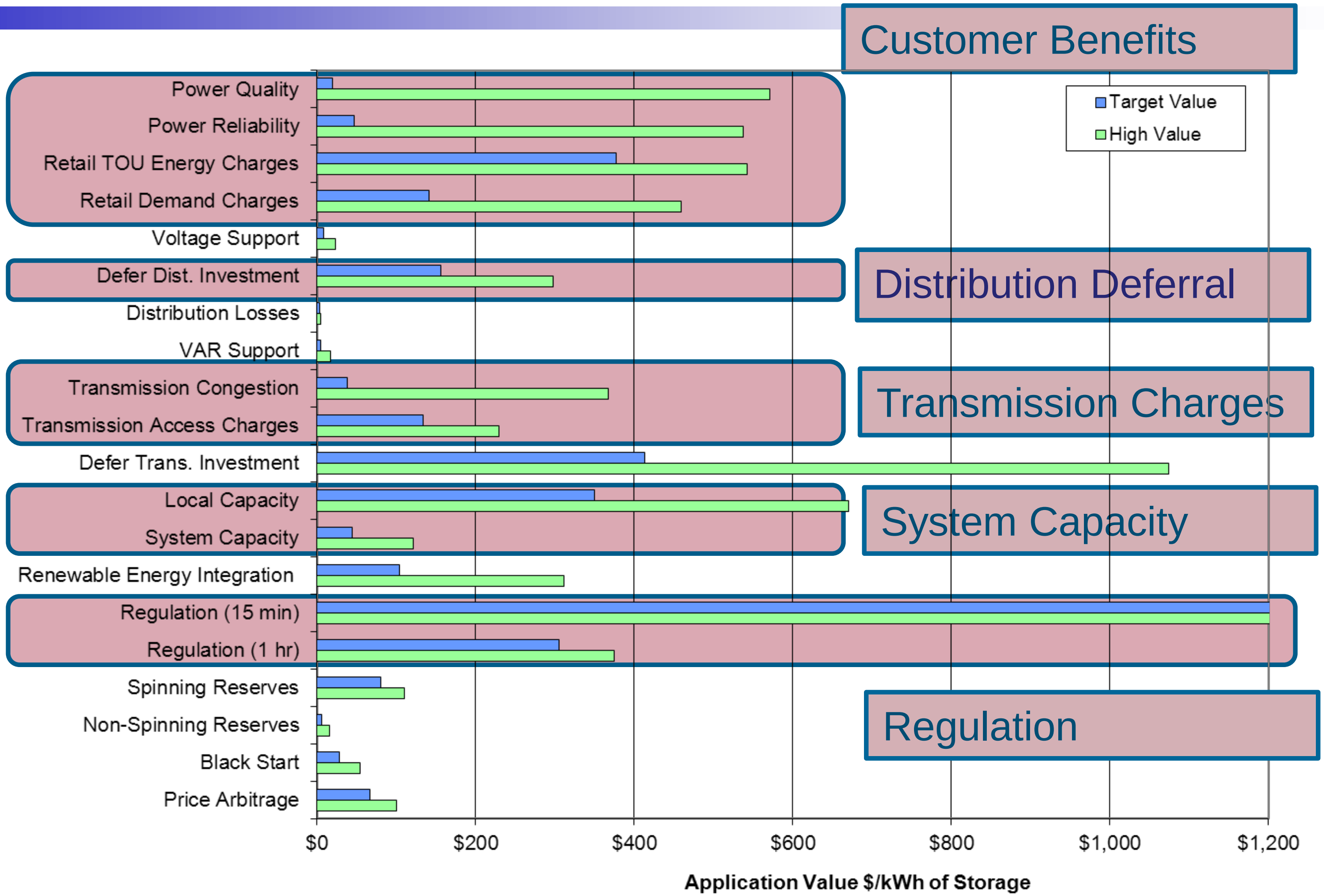
Life: years

kWh / Cycle and total cycles over life (depth of discharge, begin or end of life considerations)

Life Cycle Cost expressed as $/kWh delivered

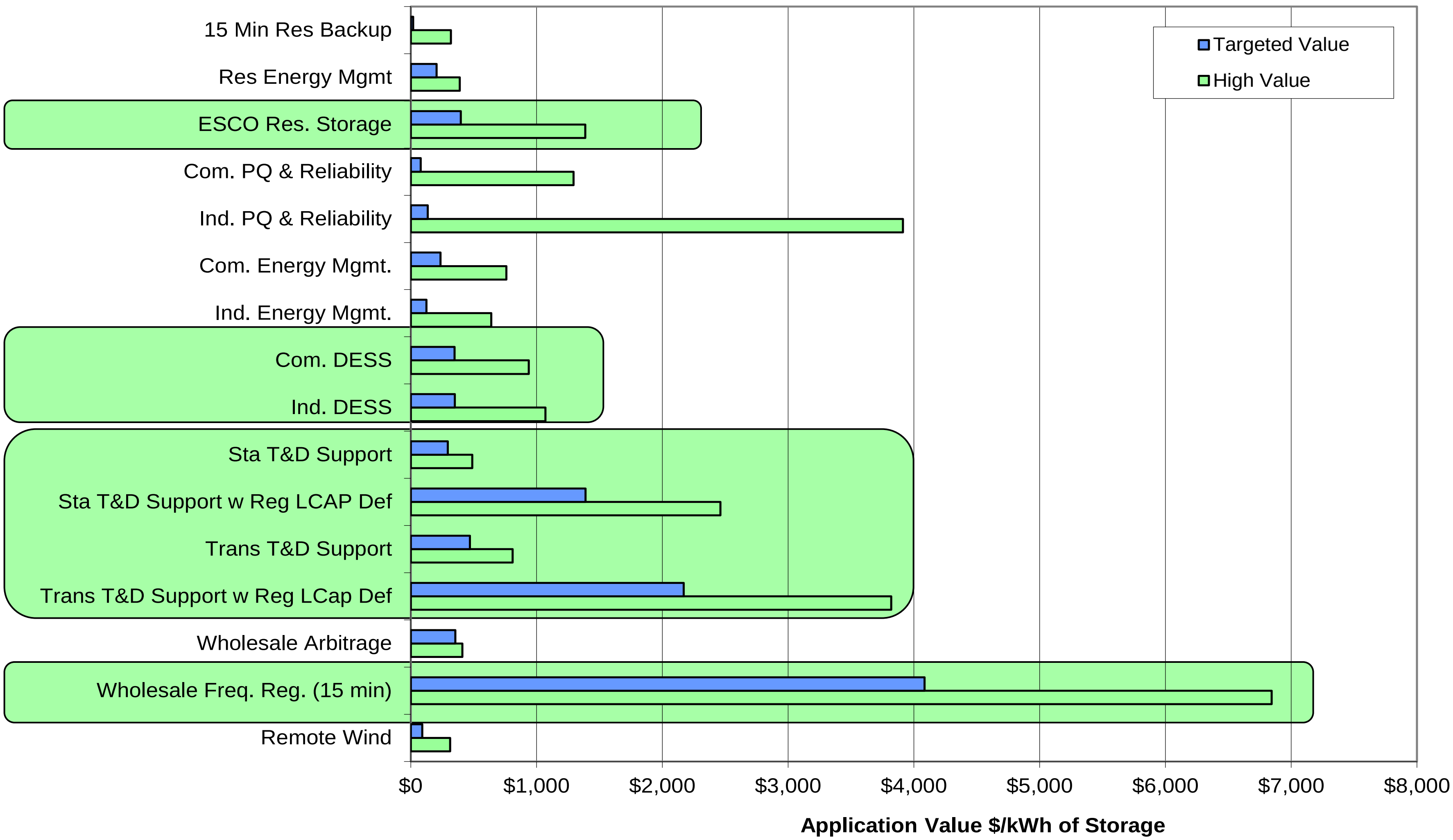
Both Methods Needed to Support Business Case

Present Value Benefits of Energy Storage by Application



* Note: for this table the benefit is modeled in isolation using a 1 MW of storage discharge capacity; 2 MWh of storage capacity;15 year life; and a 10% discount rate

Present Value Benefits of Energy Storage by Application



*End-user savings represent a loss of revenue to the utility their benefits from the regional (TRC) perspective would be lower.

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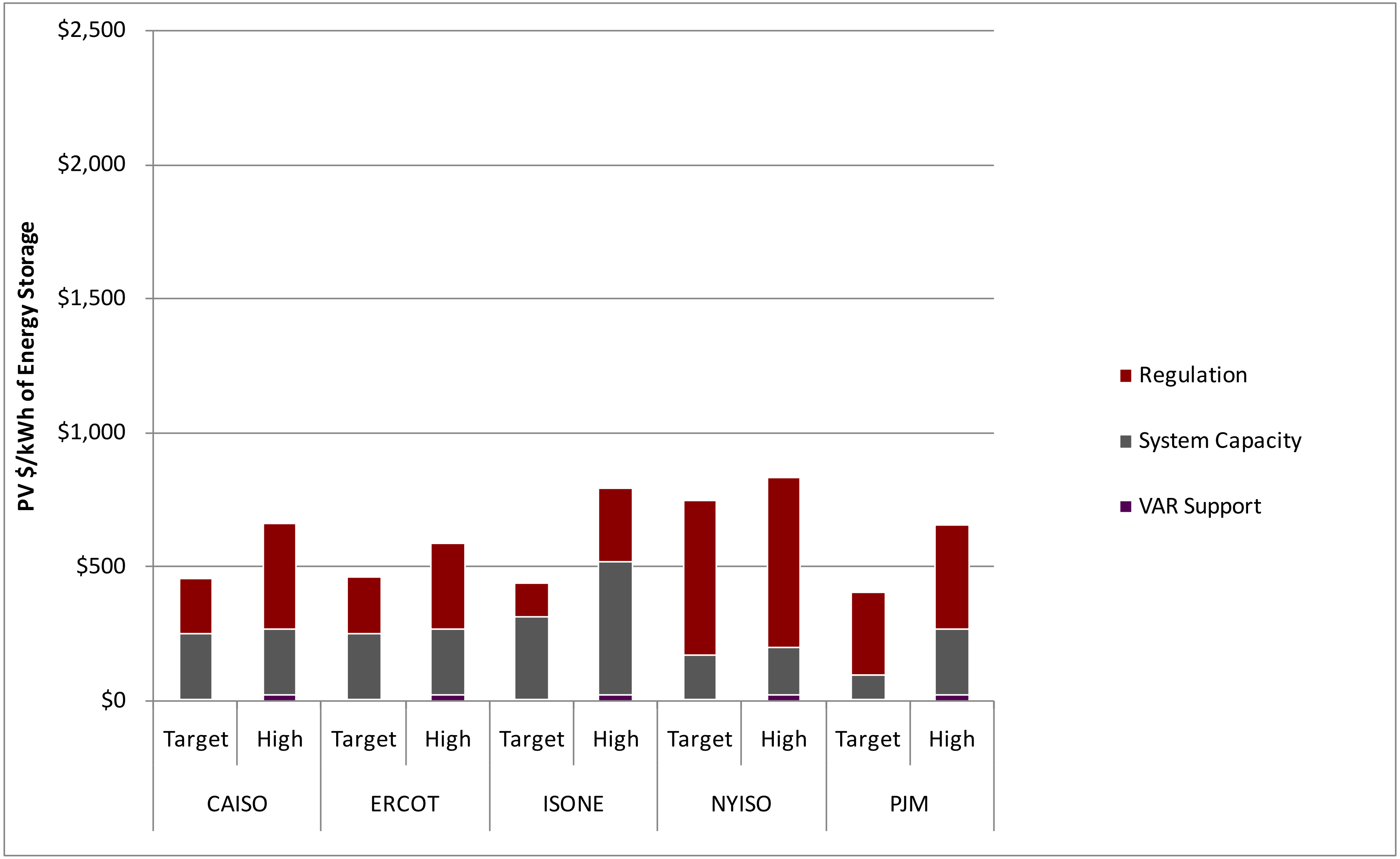
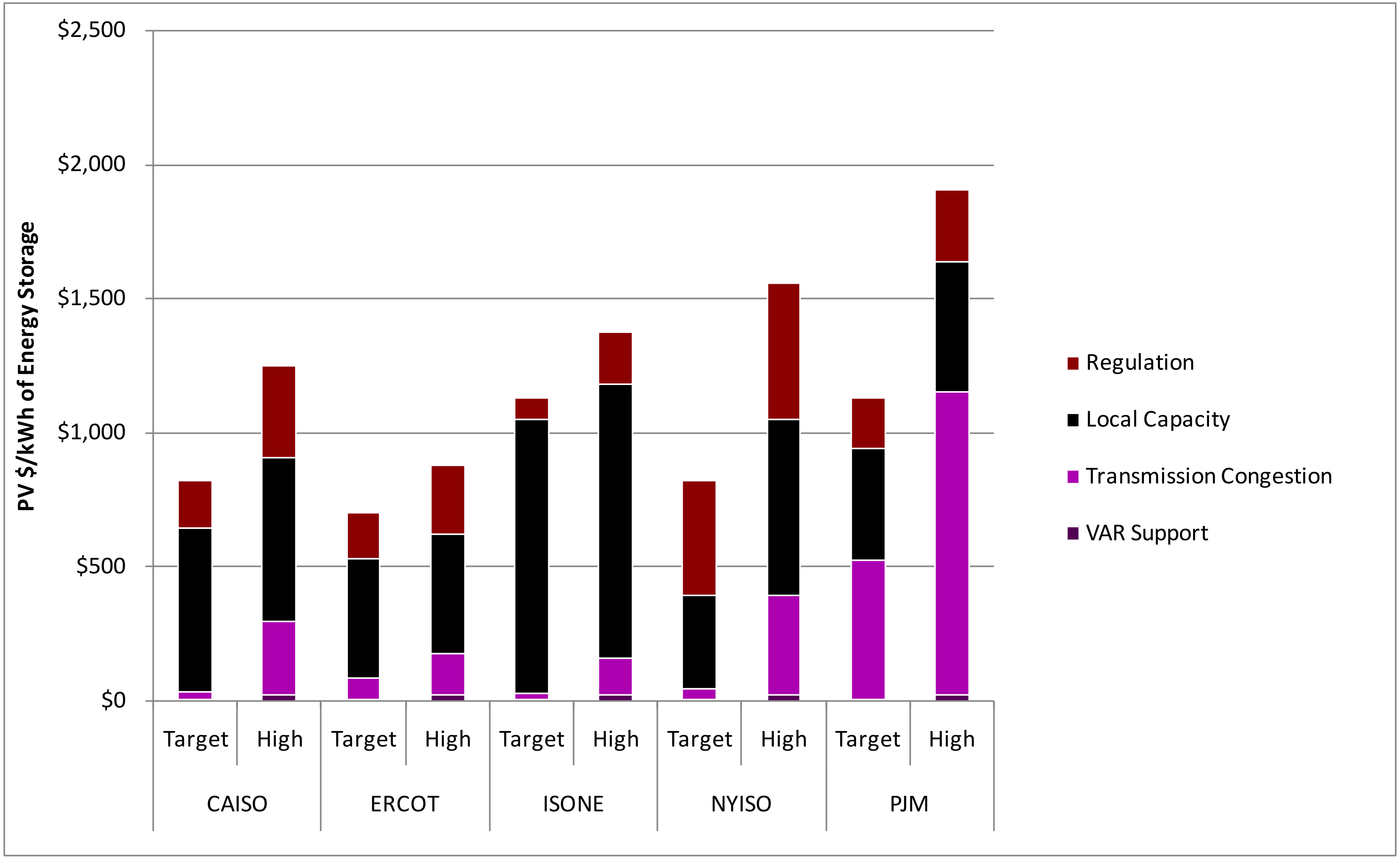
Application: Whole Sale Services – Regulation

Present Value of Benefits; Range by ISO Market



Application: Whole Sale Services
with Transmission Congestion



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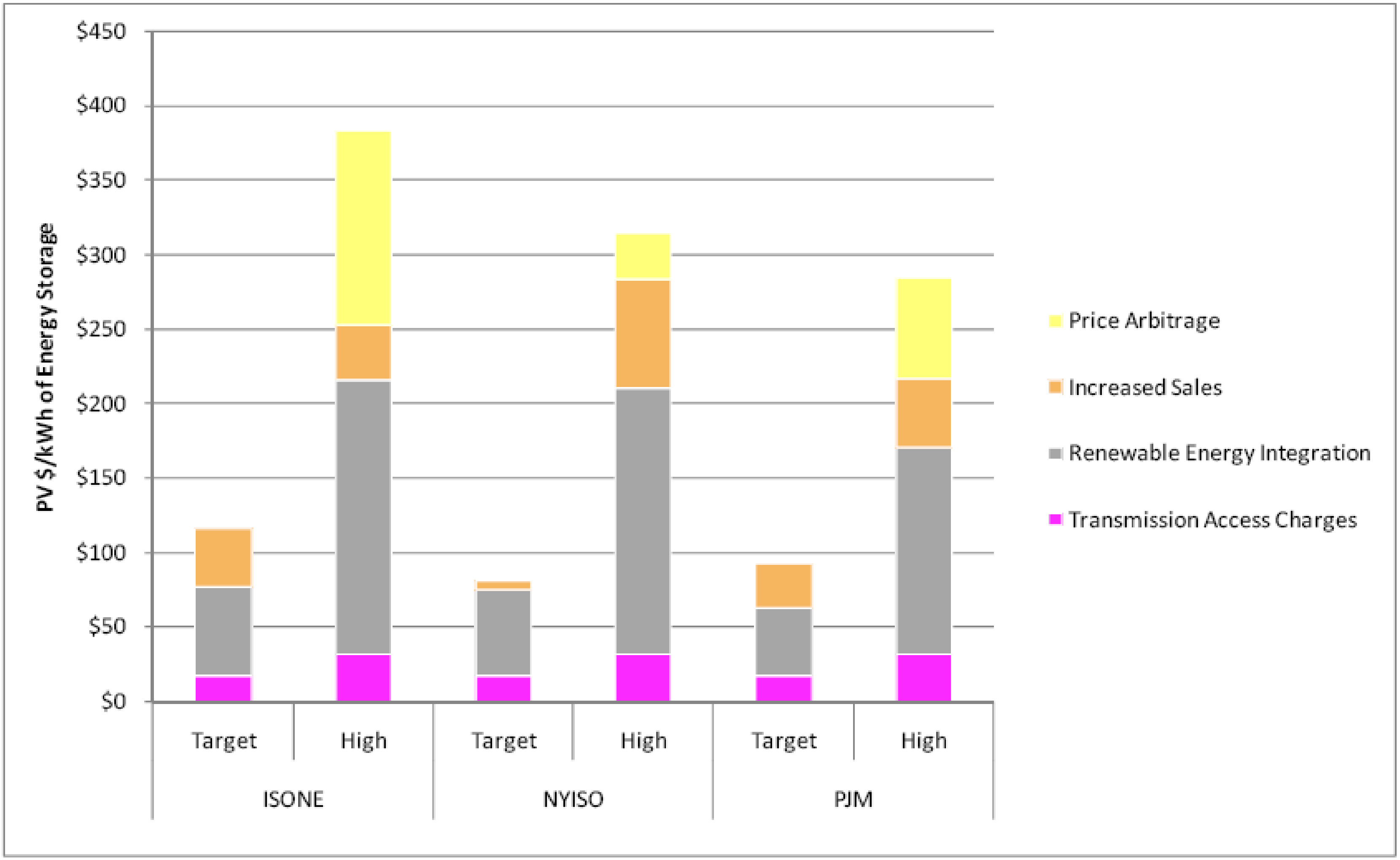
Application: Whole Sale Services - Wind



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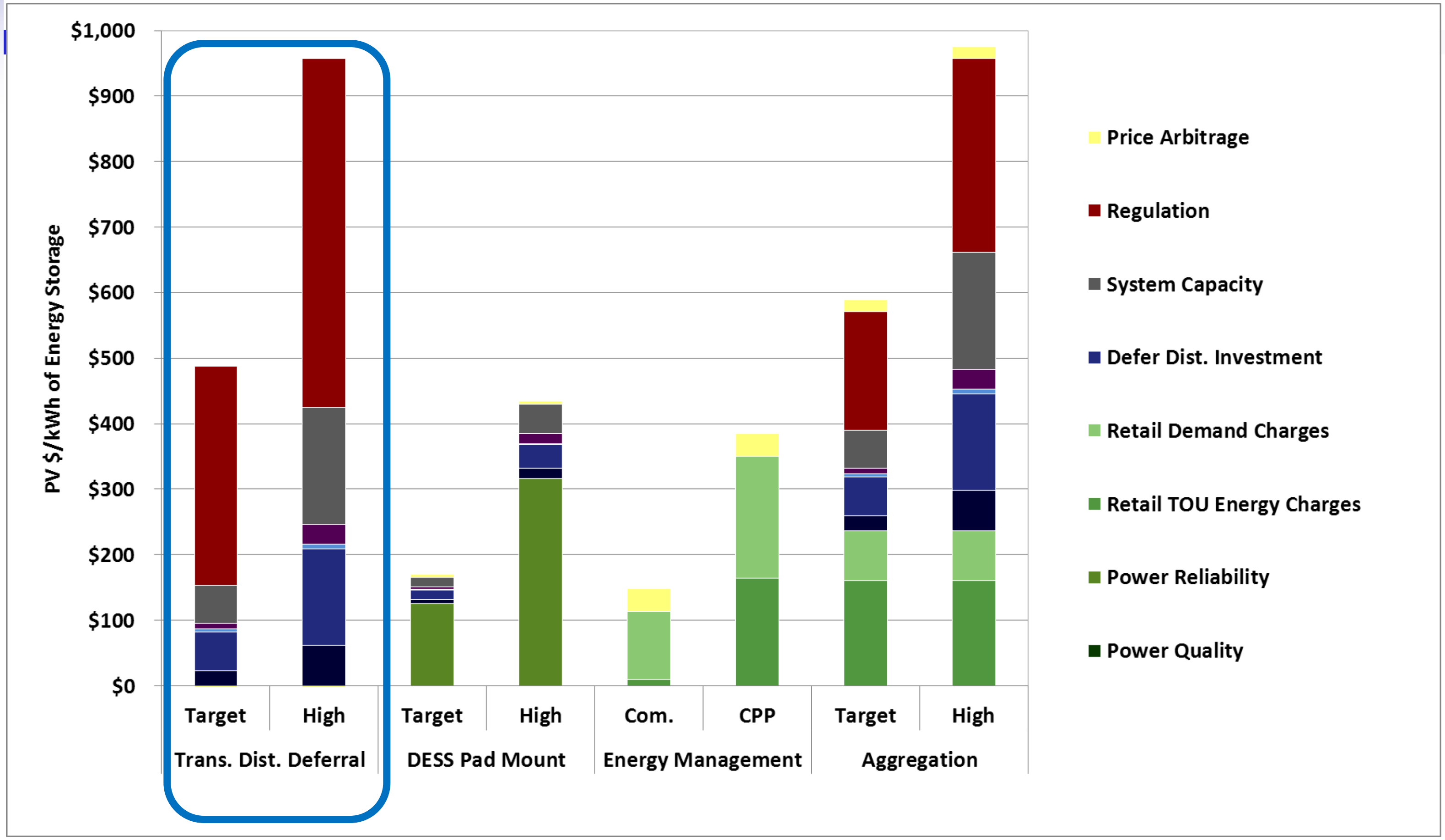
Locational Value - at Substation



Substation can provide high value System Capacity and Regulation benefits. Transportable systems enable multiple, successive deferrals.

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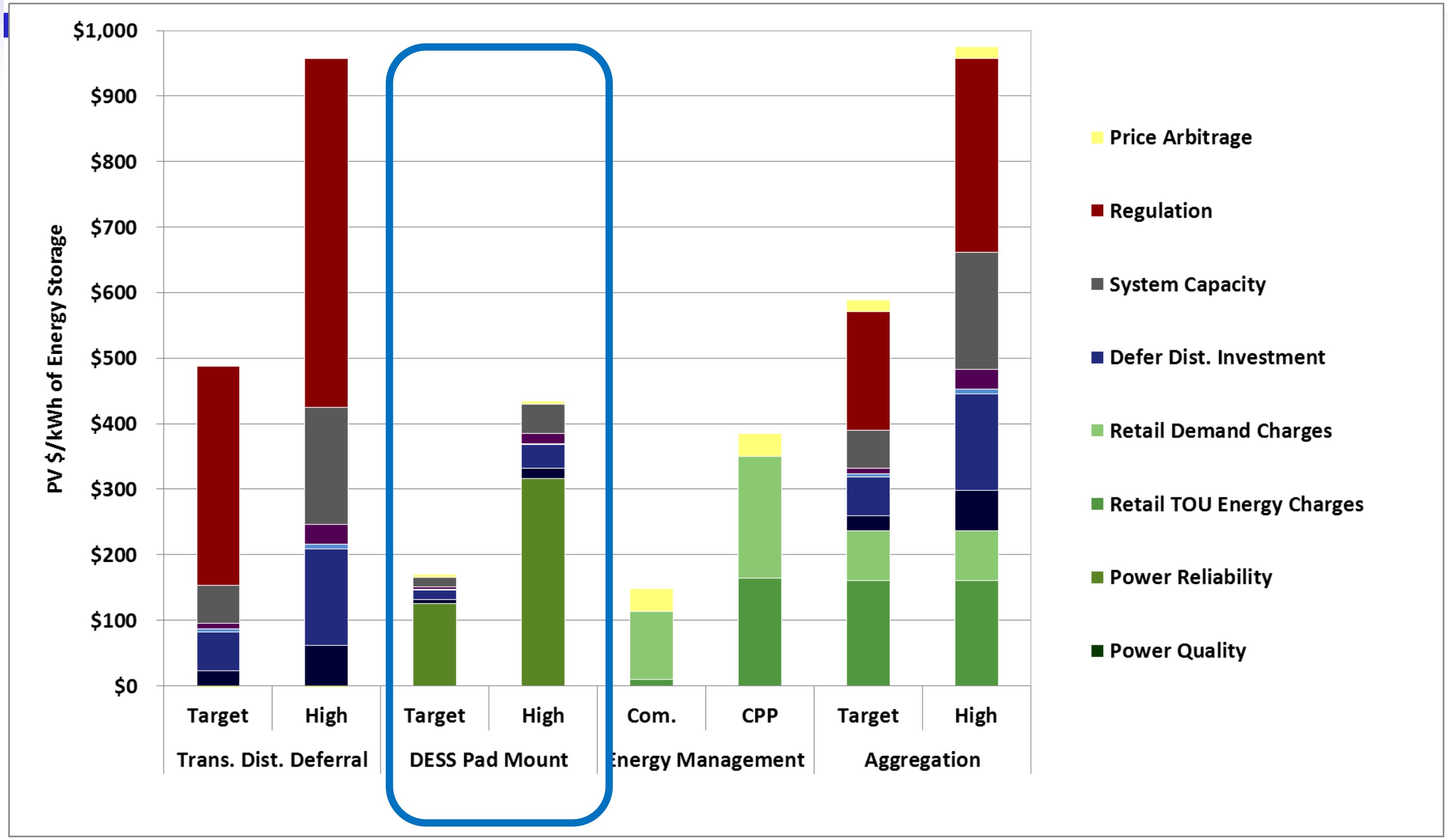
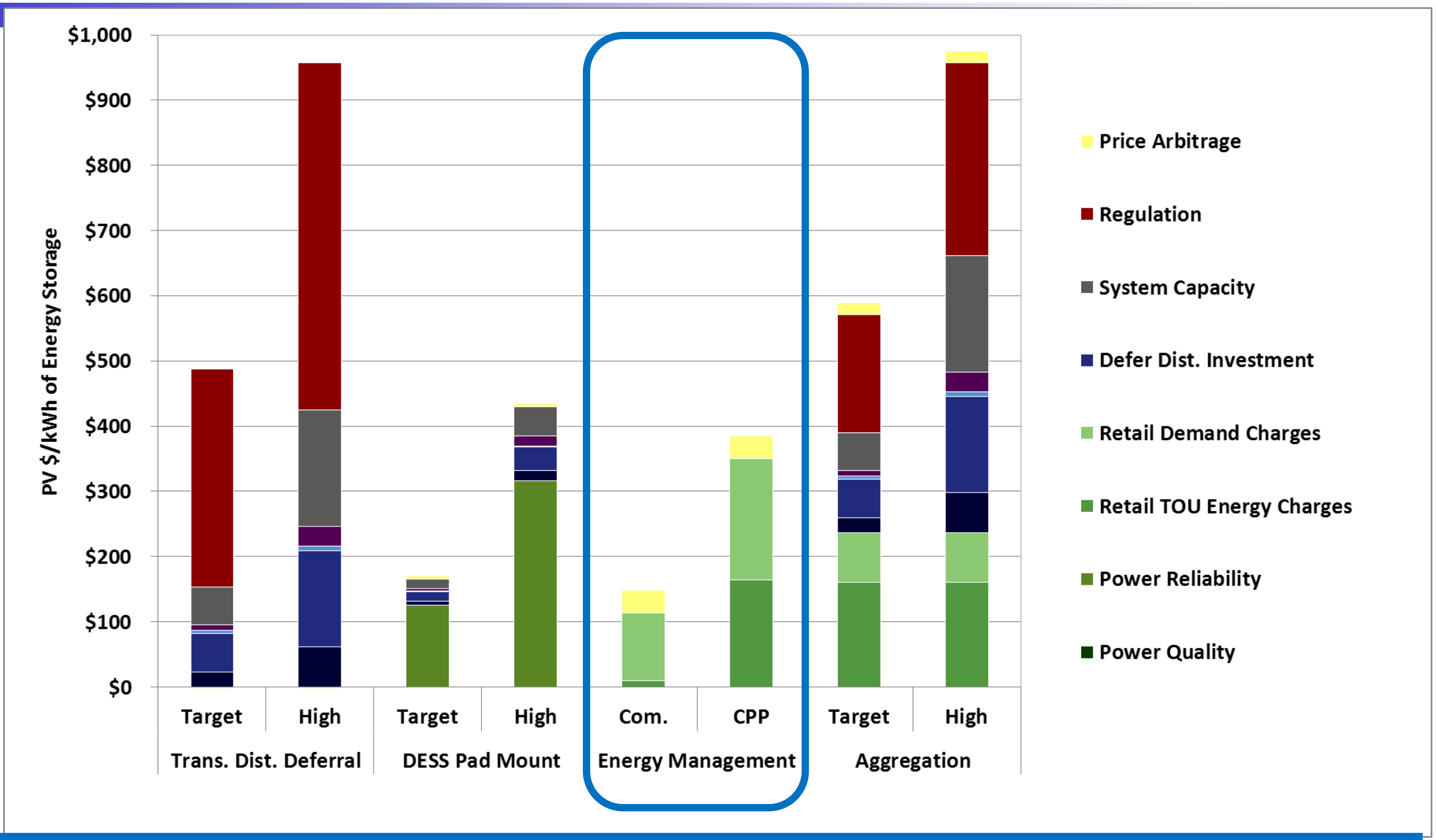
Value at Final Line Transformer - DESS



Smaller DESS systems assumed not able to provide system capacity and regulation. Customer Reliability is also limited with assumption of most (~80%) of outages downstream of final line transformer.

Value of Customer Energy Management CPP= Critical Peak Pricing



Customer can increase reliability or reduce bill, but not both. Rate savings with even with demand charge or CPP rate is modest. Assume customers with high value of service are served by non-utility owned UPS or DG.

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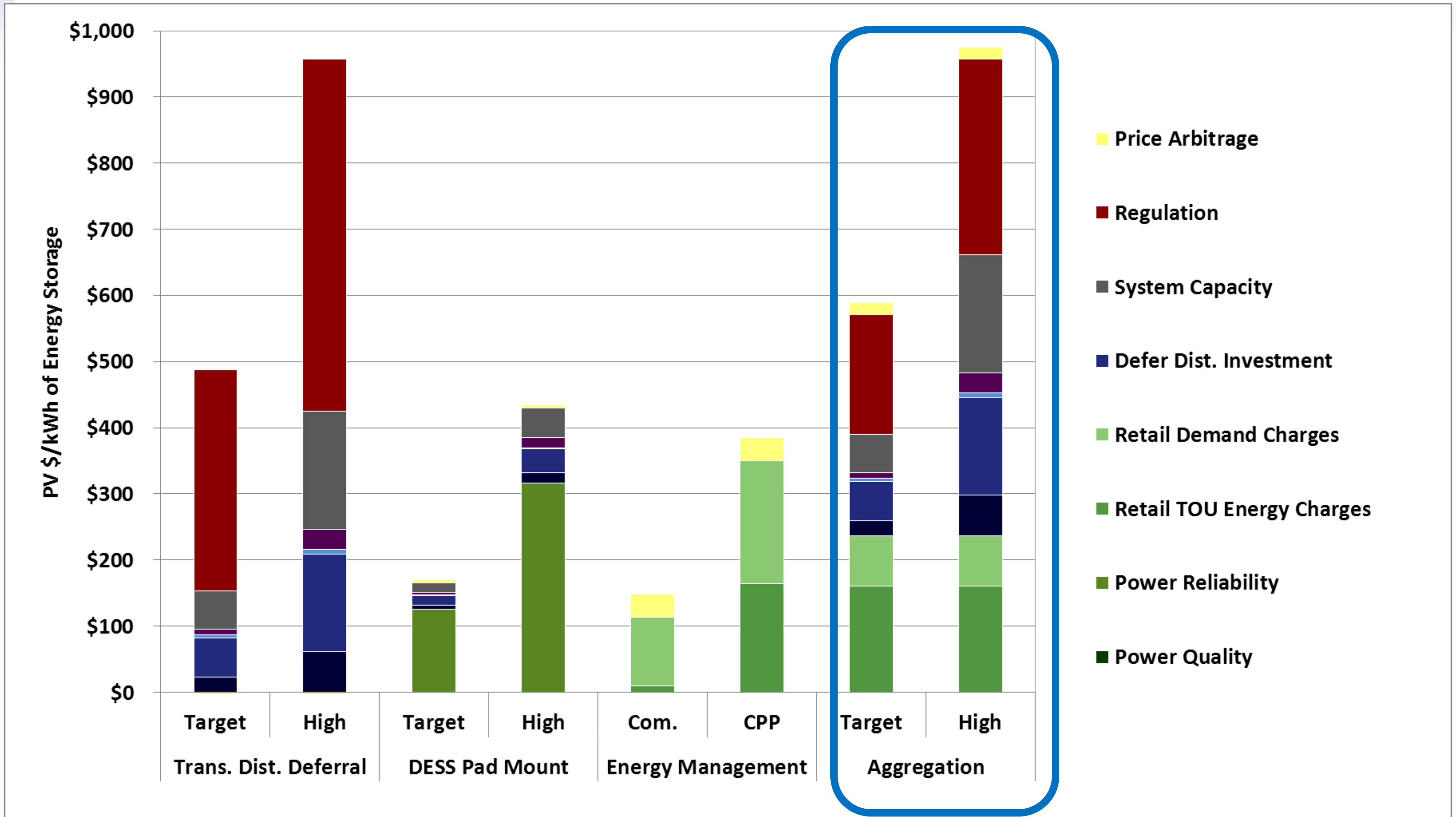
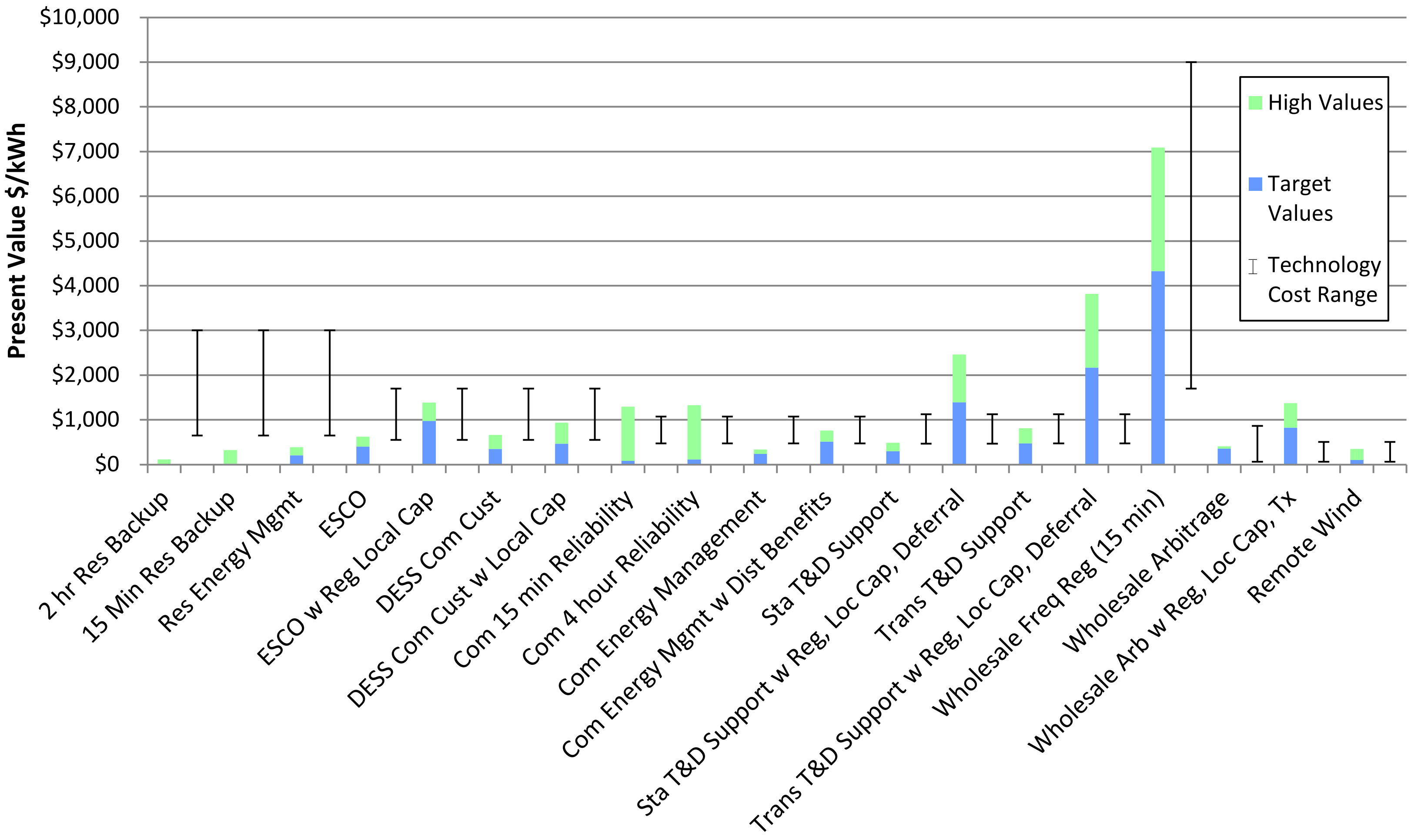
Value of Aggregation by Utility or Third Party



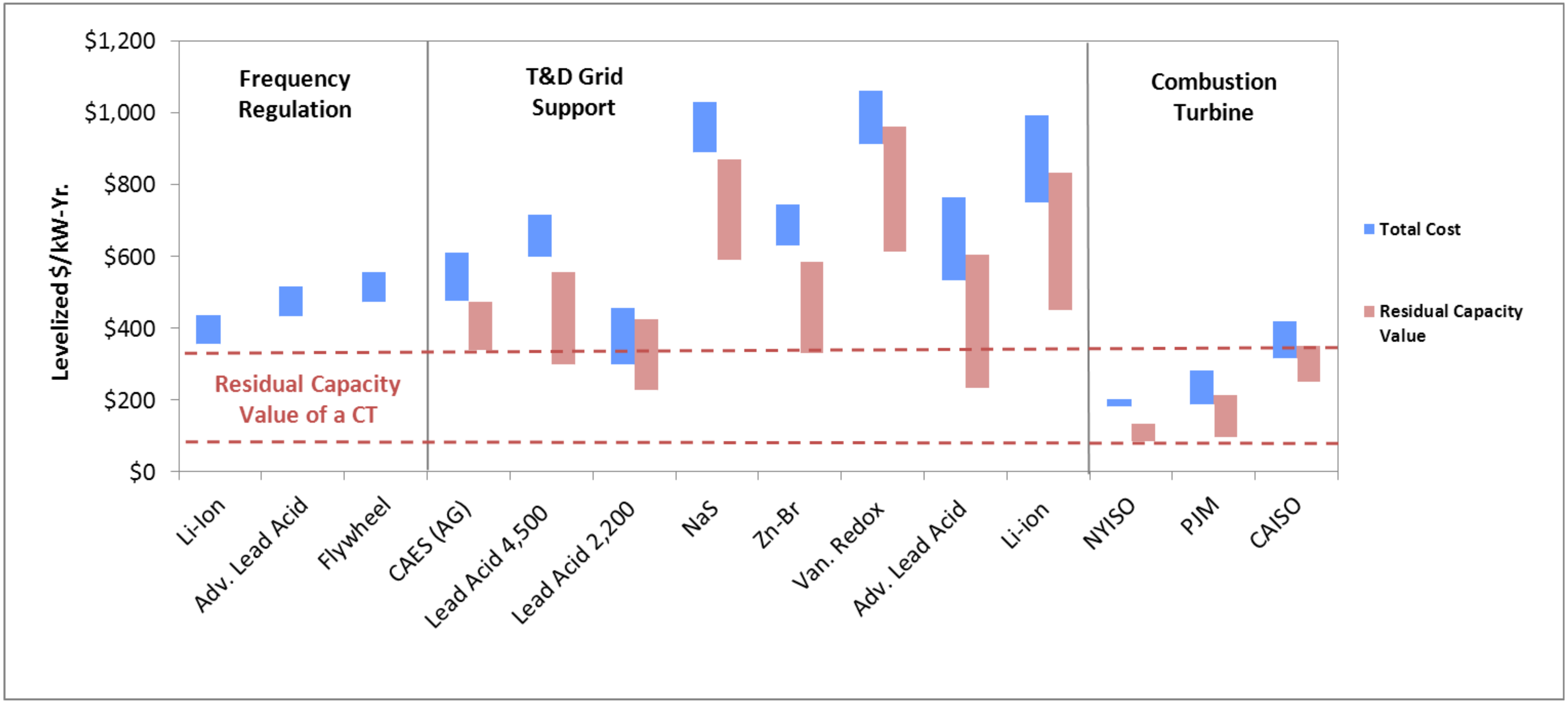
Aggregator could potentially bundle customer systems to provide system capacity and regulation, combining utility benefits and customer bill savings (which are lost revenue to the utility). Benefits shown here do not include transaction and admin costs.

Application Value / Energy Storage Cost Gap Analysis

Large Uncertainty in Costs and Performance of Storage Systems



Example of Life-Cycle Analysis Comparison "Preliminary "



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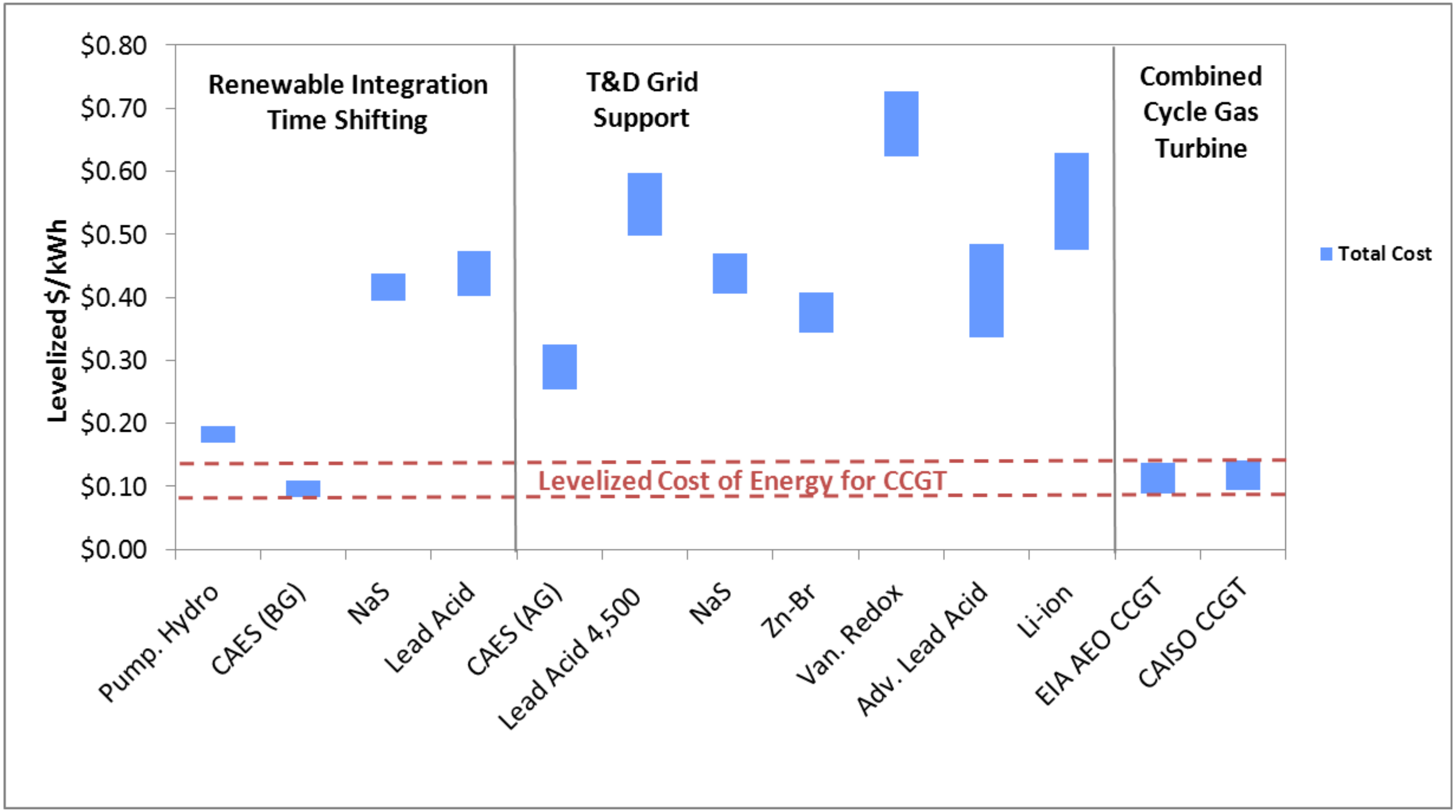

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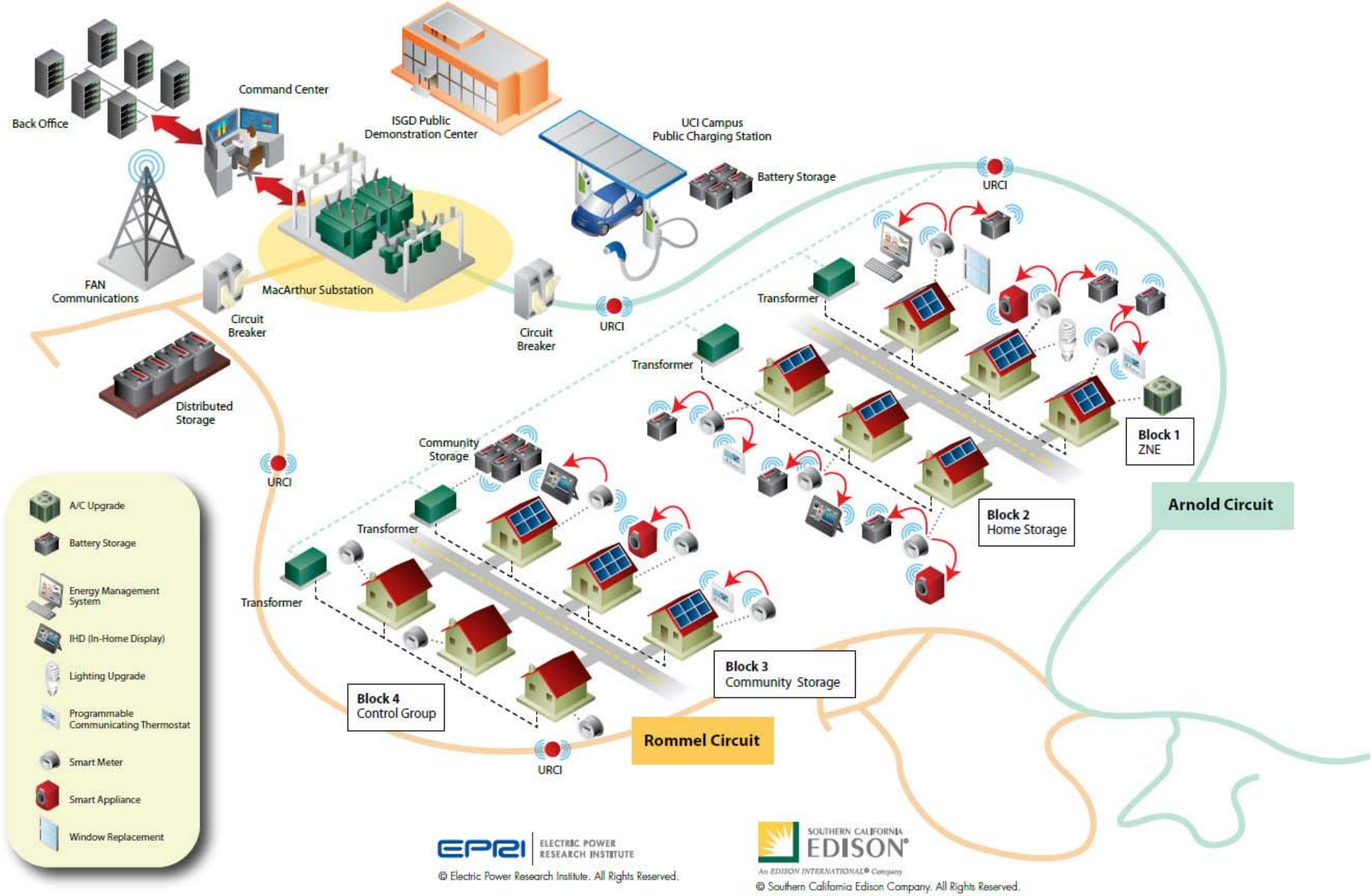
Integration Activities: Southern California Edison
Irvine Smart Grid Demonstration

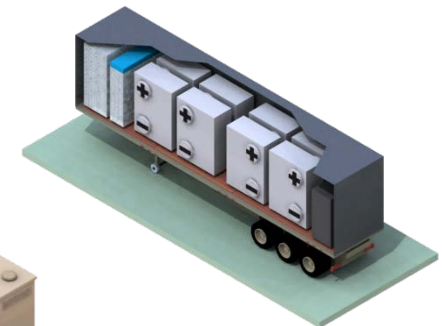


Policy Challenges
To Realize True Potential of Storage Assets

- Energy Storage systems' multi-functional characteristics complicates rules for ownership and operation among various stakeholders.
- Regulatory agencies have not defined ownership structures when storage can be used for both generation and grid uses.
- Policy rules regarding allocation of costs incurred by adding storage systems to the grid need to be more clearly developed.
- Energy storage could enable bi-directional energy flows creating problems for current tariff, billing and metering approaches.
- New market structures and rules may be needed to accommodate and reap the benefits of emerging energy storage systems.

Summary and EPRI Perspectives

- Grid Energy Storage Deployment is in its Infancy
- Few systems are validated in utility grid applications
- Significant uncertainties in cost, performance and life make economic comparisons challenging at this time



- Applications must realize multiple operational uses across the energy value chain
- CAES – lowest cost (near-term) option for Bulk Storage > 10 hrs; Large Demos Planned.

- Li-ion – potentially lowest cost (longer-term) for distributed storage < 4 hrs; Emerging Demo Opportunity
- **Key Opportunities**:
  - Standardize functional & application requirements
  - Test, validate storage solution(s) capability
  - Policy to enable monetized benefits as part of Smart Grid program plans
  - Leverage developments in electric transportation storage platforms for stationary grid use cases.

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