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Energy Storage Applications and Economics

Costs, Benefits, Revenue

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California Energy Commission
IEPR Committee Workshop
Energy Storage for Renewable Integration
Sacramento, CA

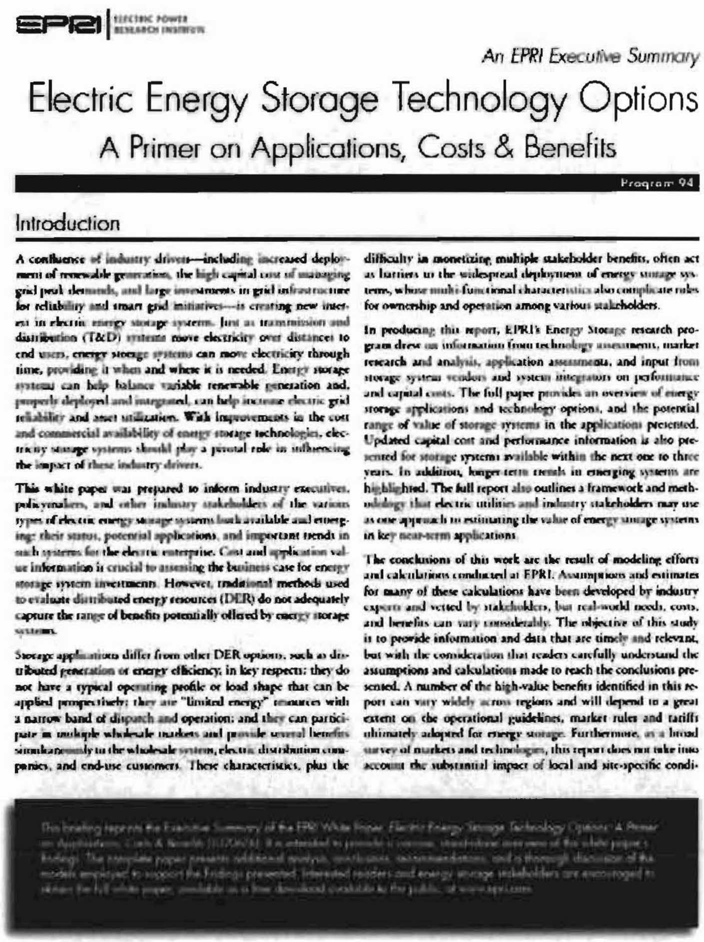
April 28, 2011

Panel Questions

- *What are the costs estimates for the increased use of energy storage?*
- *How can the benefits of energy storage best be quantified?*
- *What revenue mechanisms are available to ensure energy storage plays the appropriate role in the California grid of the future?*
- *What will be the specific economics and cost-benefit data that needs to be developed to support the implementation of the Assembly Bill 2514 Energy Storage development, demonstration, and deployment plan activities?*

EPRI Research: See: EPRI 1020676

Applications, Benefits and Costs of Energy Storage Systems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An EPRI Executive Summary

Electric Energy Storage Technology Options

A Primer on Applications, Costs & Benefits

Program 94

Introduction

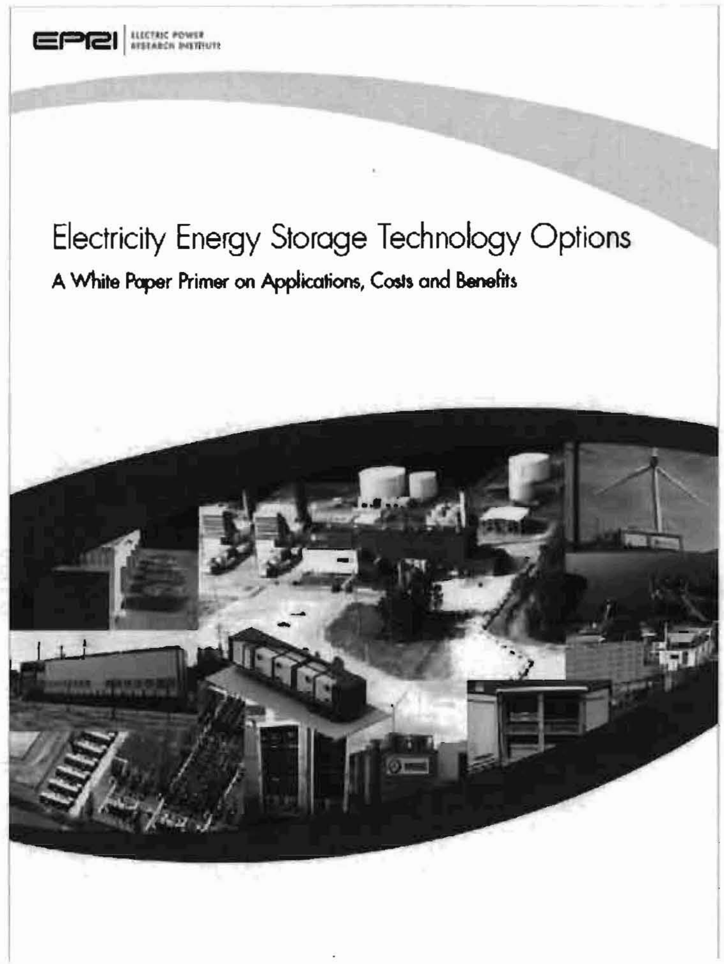
A confluence of industry drivers—including increased deployment of renewable generation, the high capital cost of managing grid peak demands, and large investments in grid infrastructure for reliability and smart grid initiatives—is creating new interest in electric energy storage systems. Just as transmission and distribution (T&D) systems move electricity over distances to end users, energy storage systems can move electricity through time, providing it when and where it is needed. Energy storage systems can help balance variable renewable generation and, properly deployed and integrated, can help increase electric grid reliability and asset utilization. With improvements in the cost and commercial availability of energy storage technologies, electricity storage systems should play a pivotal role in influencing the impact of these industry drivers.

This white paper was prepared to inform industry executives, policymakers, and other industry stakeholders of the various types of electric energy storage systems both available and emerging: their status, potential applications, and important trends in such systems for the electric enterprise. Cost and application value information is crucial to assessing the business case for energy storage system investments. However, traditional methods used to evaluate distributed energy resources (DER) do not adequately capture the range of benefits potentially offered by energy storage systems.

Storage applications differ from other DER options, such as distributed generation or energy efficiency, in key respects: they do not have a typical operating profile or load shape that can be applied prospectively; they are "limited energy" resources with a narrow band of dispatch and operation; and they can participate in multiple wholesale markets and provide several benefits simultaneously to the wholesale system, electric distribution companies, and end-use customers. These characteristics, plus the difficulty in monetizing multiple stakeholder benefits, often act as barriers to the widespread deployment of energy storage systems, whose multi-functional characteristics also complicate roles for ownership and operation among various stakeholders.

In producing this report, EPRI's Energy Storage research program drew on information from technology assessments, market research and analysis, application assessments, and input from storage system vendors and system integrators on performance and capital costs. The full paper provides an overview of energy storage applications and technology options, and the potential range of value of storage systems in the applications presented. Updated capital cost and performance information is also presented for storage systems available within the next one to three years. In addition, longer-term trends in emerging systems are highlighted. The full report also outlines a framework and methodology that electric utilities and industry stakeholders may use as one approach to estimating the value of energy storage systems in key near-term applications.

The conclusions of this work are the result of modeling efforts and calculations conducted at EPRI. Assumptions and estimates for many of these calculations have been developed by industry experts and vetted by stakeholders, but real-world needs, costs, and benefits can vary considerably. The objective of this study is to provide information and data that are timely and relevant, but with the consideration that readers carefully understand the assumptions and calculations made to reach the conclusions presented. A number of the high-value benefits identified in this report can vary widely across regions and will depend to a great extent on the operational guidelines, market rules and tariffs ultimately adopted for energy storage. Furthermore, as a broad survey of markets and technologies, this report does not take into account the substantial impact of local and site-specific condi-



Capital Costs of Energy Storage Options – Examples

See: EPRI 1020676

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)	80-82	$1500-$4300	250-430
Compressed Air	ISO services Wind Integration	Demo	10-20 (>13000)	4000 Btu/kWh 0.7 ER	$960-$1250	60-125
NAS	Grid Support Wind Integration	Mature	6 (4500)	80	$3200-$4200	445-555
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	ISO Services Grid Support C&I Energy Mgt PV Integration	Demo	0.25 (>10000) 2 (5000)	90	1200-1500 2100-4650	4800-6000 1050-1550
Fly Wheels	ISO Services	Demo	0.25 (>>20,000)	90	1900-2250	7800-7900

EPRI Ref. Designs: Bulk Storage Options for Renewable Integration

Storage System Characteristics and Costs – 2010 Findings

Technology Option/ Characteristics	CAES Above Ground	NAS	A-Pb Adv. Lead Acid	Zn/Br Redox	Vanadium Redox	Fe/Cr Redox	Zn/Air Redox
Unit Capacity MW MWH	50 250	50 300	50 250	50 250	50 250	50 250	50 250
Ac-Ac Efficiency,% (heat rate)* Energy Ratio**	-------- (4000) 1.0	.75-80	85-90	60-65	75-78	70-75	70-75
Foot print Ft2/kW	1.6	2.0	1.9 - 5.1	0.9	2.0	1.1	1.3
Total Capital Costs ($/kW)	1700-1950	3060-3200	1750-4900	1660-1800	3500-3700	1800	1400-1700
Technical Maturity and readiness	Demo	Commercial	Commercial-Demo	Demo	Demo	R&D Lab	R&D Lab

*Heat rate is Btu/ kWh, LHV

**Energy ratio is kWh - in / kWh-out

Other Emerging Storage Systems Also Need Consideration

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

Estimated Range of Benefits $/kW-h and $/kW

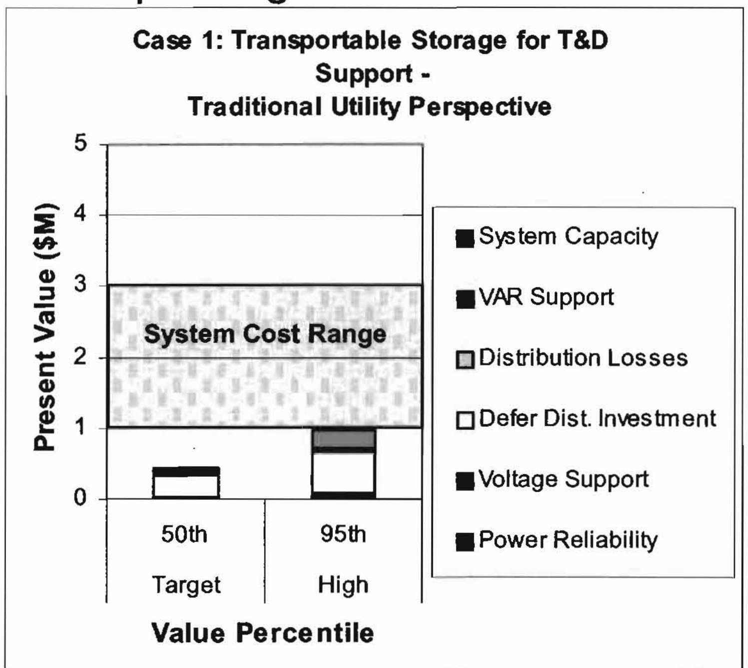
Target (Average) and High (95th percentile) Estimates across 5 ISO Regions Studied

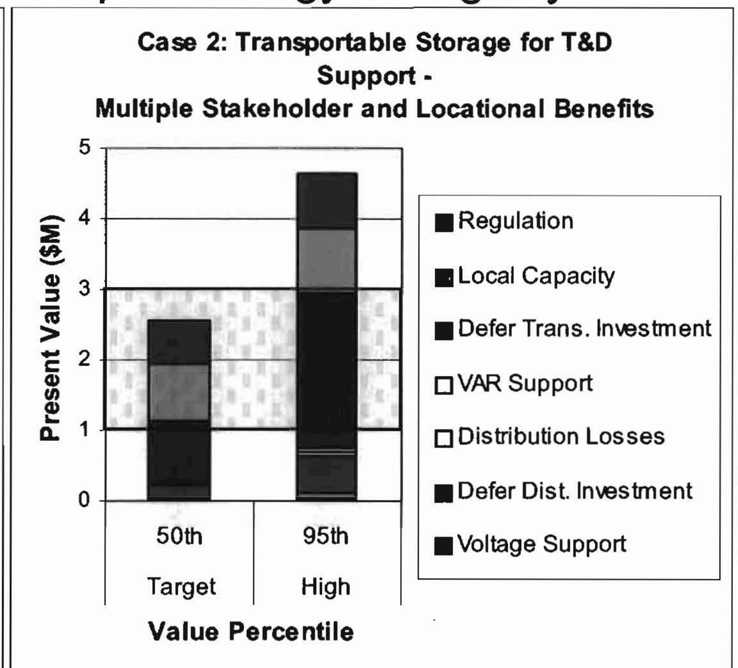
			PV $/kW-h		PV $/kW	
Value Chain	**Benefit**		**Target**	**High**	**Target**	**High**
End User	1	Power Quality	19	96	571	2,854
	2	Power Reliability	47	234	537	2,686
	3	Retail TOU Energy Charges	377	1,887	543	2,714
	4	Retail Demand Charges	142	708	459	2,297
Distribution	5	Voltage Support	9	45	24	119
	6	Defer Distribution Investment	157	783	298	1,491
	7	Distribution Losses	3	15	5	23
Transmission	8	VAR Support	4	22	17	83
	9	Transmission Congestion	38	191	368	1,838
	10	Transmission Access Charges	134	670	229	1,145
	11	Defer Transmission Investment	414	2,068	1,074	5,372
System	12	Local Capacity	350	1,750	670	3,350
	13	System Capacity	44	220	121	605
	14	Renewable Energy Integration	104	520	311	1,555
ISO Markets	15	Fast Regulation (1 hr)	1,152	1,705	1,152	1,705
	16	Regulation (1 hr)	514	761	514	761
	17	Regulation (15 min)	4,084	6,845	1,021	1,711
	18	Spinning Reserves	80	400	110	550
	19	Non-Spinning Reserves	6	30	16	80
	20	Black Start	28	140	54	270
	21	Price Arbitrage	67	335	100	500

Modeling Benefits – Approach

Total Resource Cost Test (TRC)[1]

- "Bottom's Up"- Application-based value analysis across five (5) ISO regions
- "Stacked" benefits aggregate multiple stakeholders
- Target (50th percentile) and High (95th percentile) values defined
- Compare against total cost of ownership for energy storage system





Example values shown for a 2 MWh storage system in the PJM market

1. TRC is Proxy for maximum allowable installed capital cost of energy storage system

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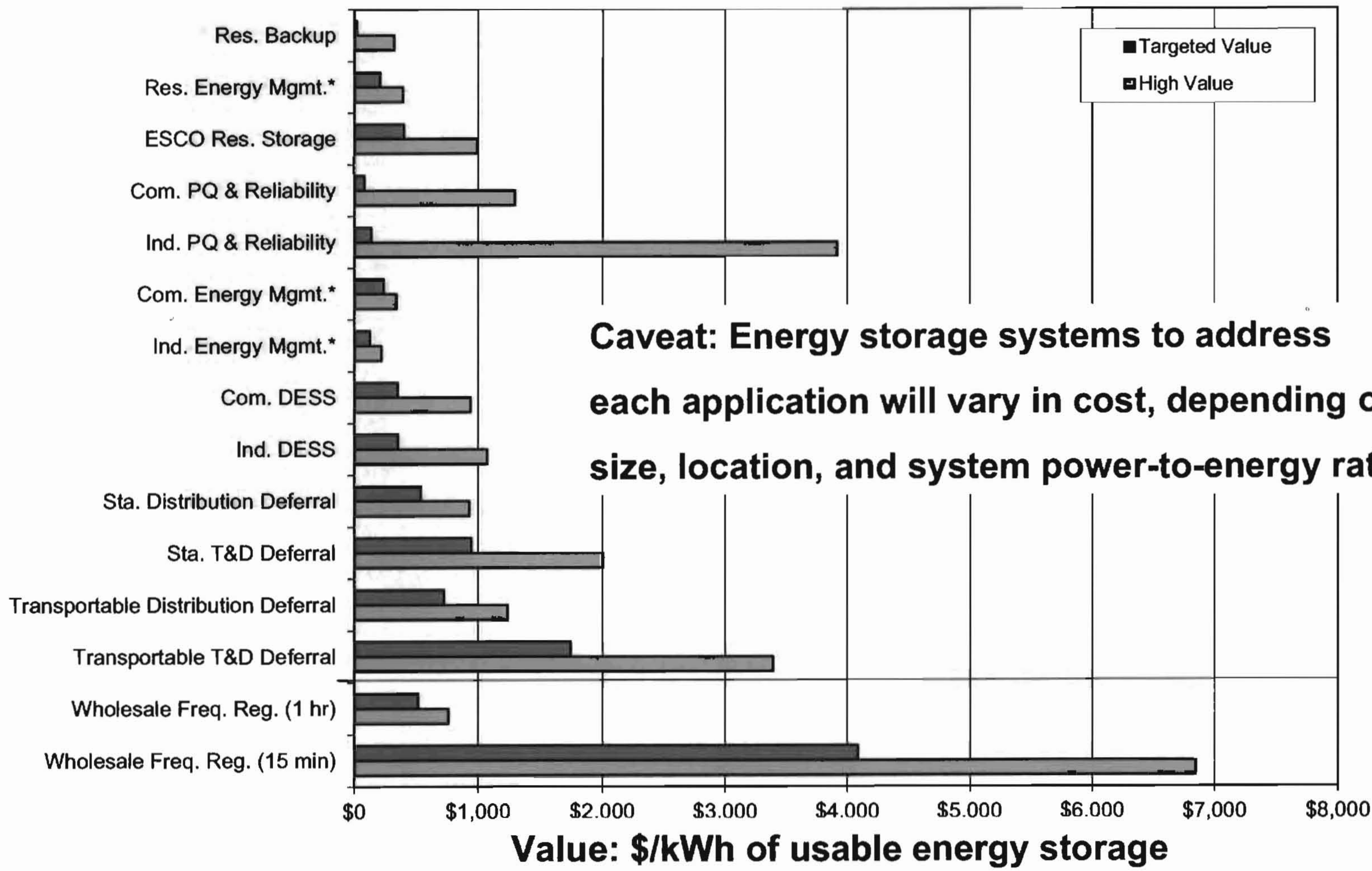
Summary of Application Value Analysis
Total Resource Cost Test (TRC)



Caveat: Energy storage systems to address each application will vary in cost, depending on size, location, and system power-to-energy ratio.

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Summary of Application Value Analysis

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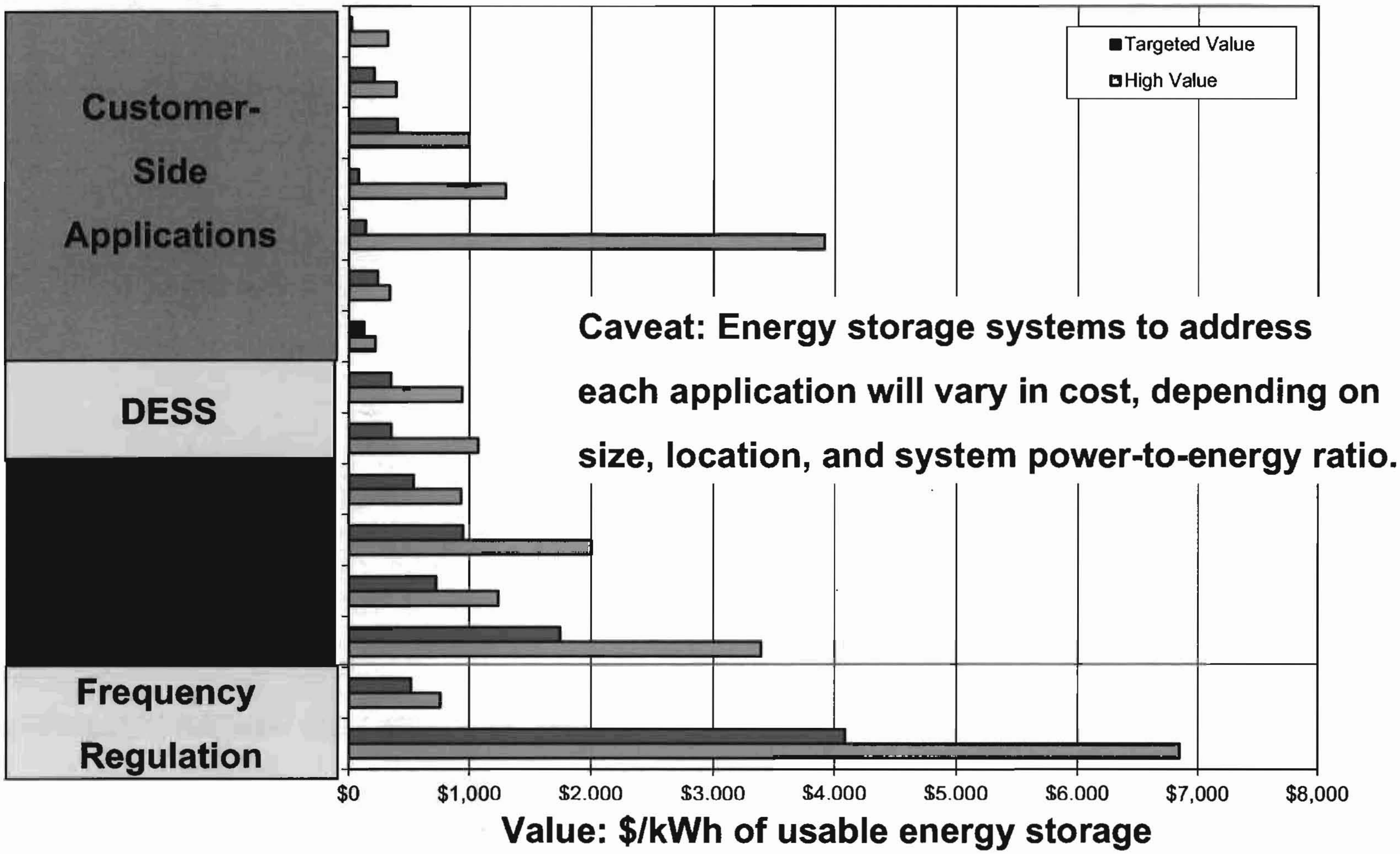

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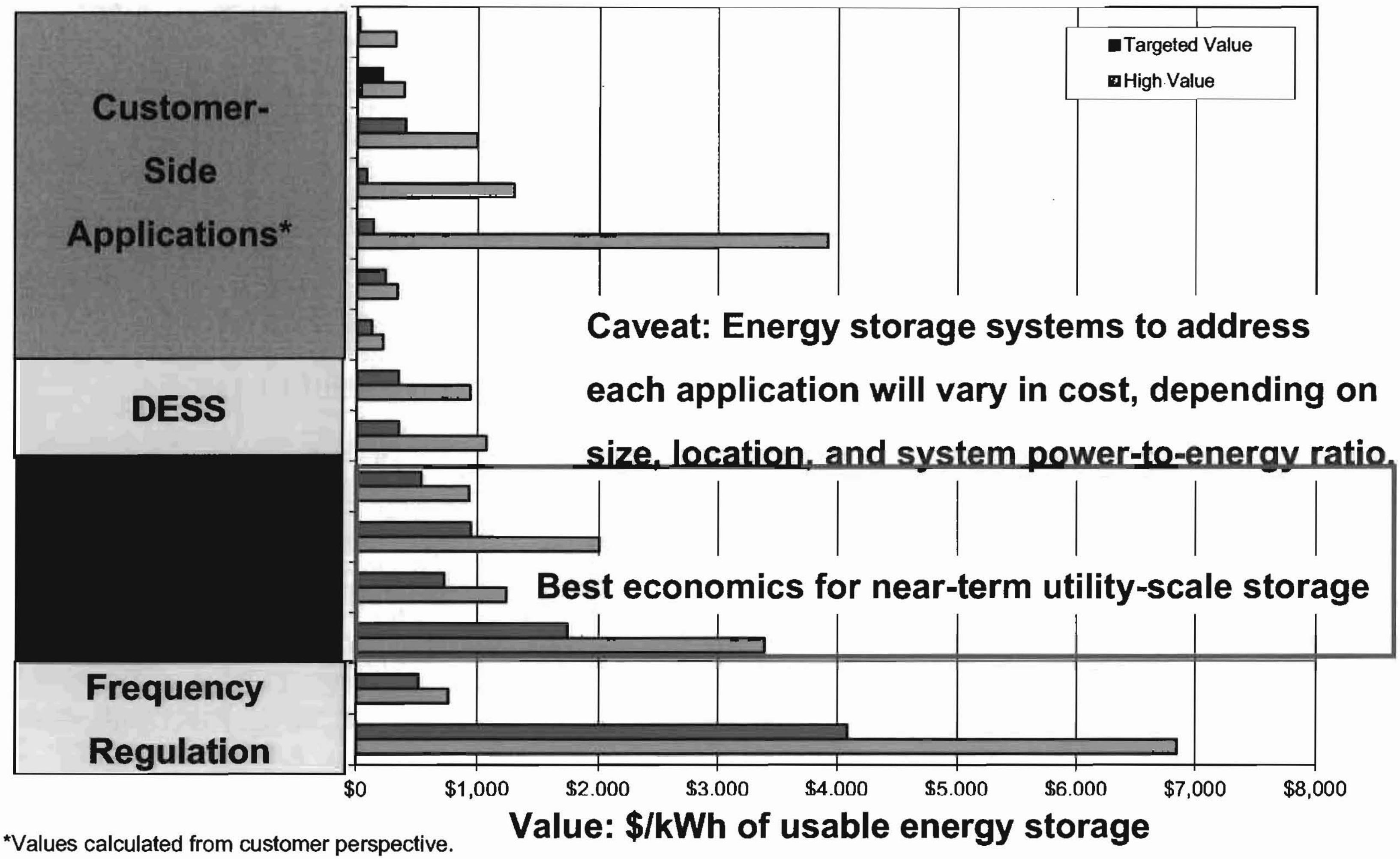

*Values calculated from customer perspective.

TOU rates and demand charge savings represent loss of utility revenue

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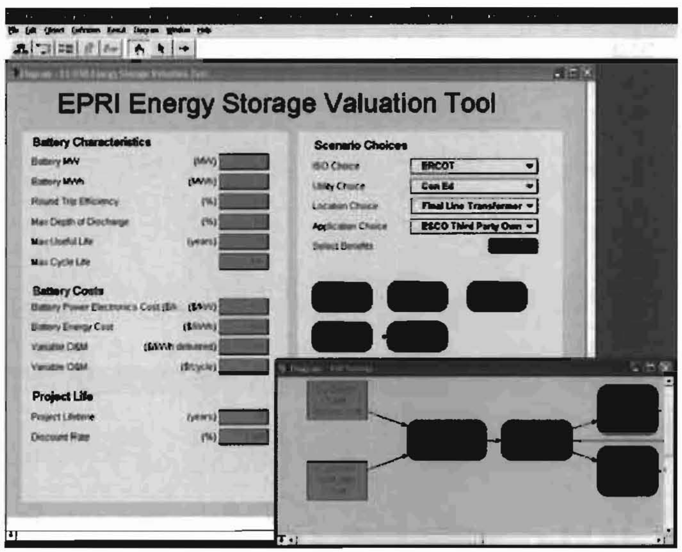
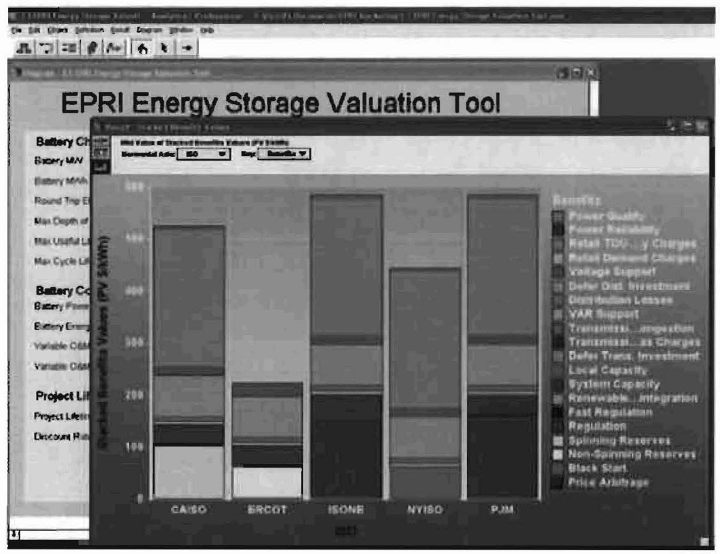
Energy Storage Valuation Tool 2011 (V3.0)

Based on Analytica software platform

- **EPRI Storage Program Goals for 2011:**
  - Deliver User-friendly, robust platform for future enhancements
  - Enable deep understanding of 2010 energy storage value analysis and embedded assumptions
  - Ability to tailor site-specific analysis on any utility system
  - Cost / benefit analysis
  - Transparent assumptions and analysis for future public stakeholder use





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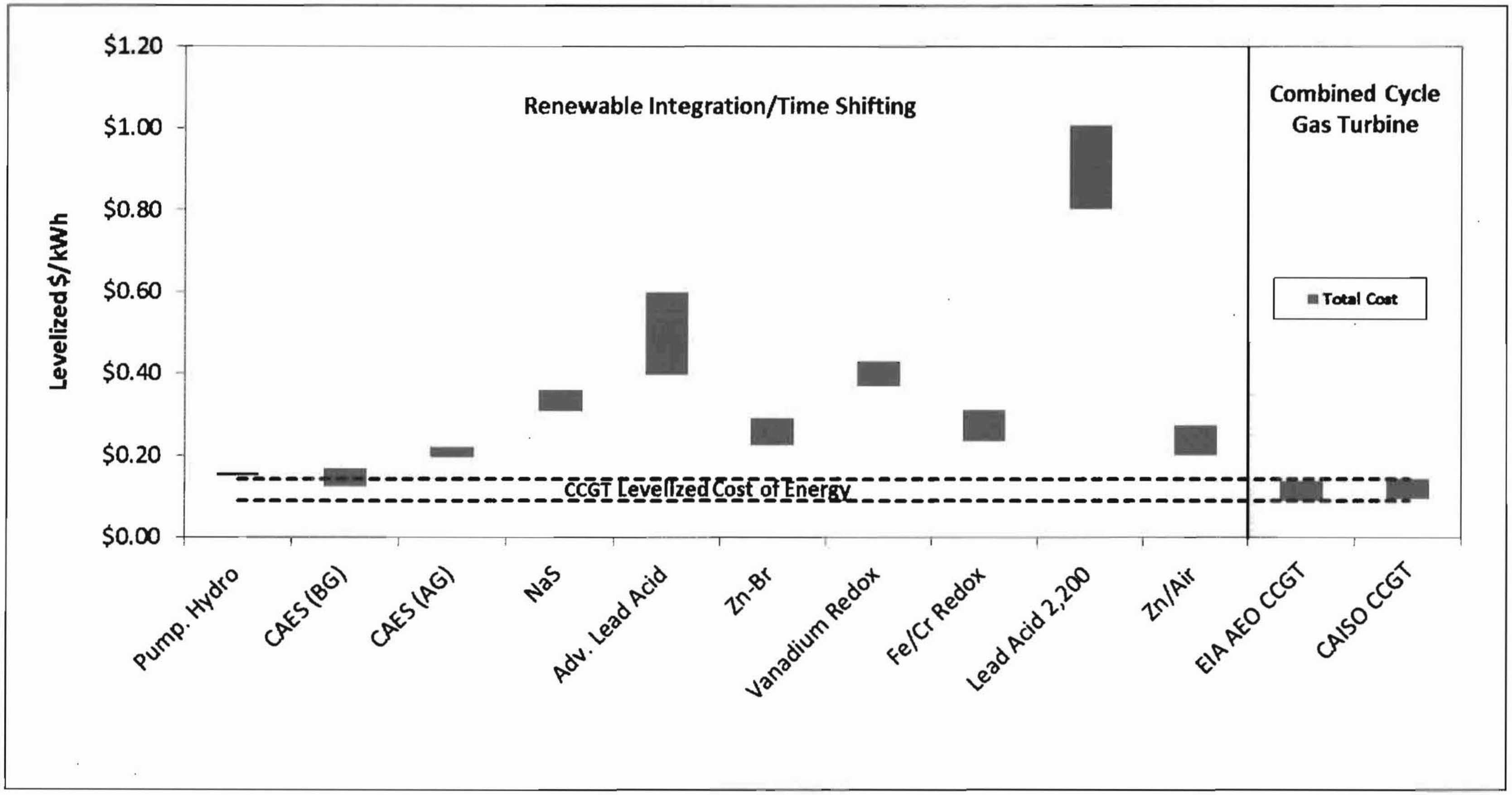
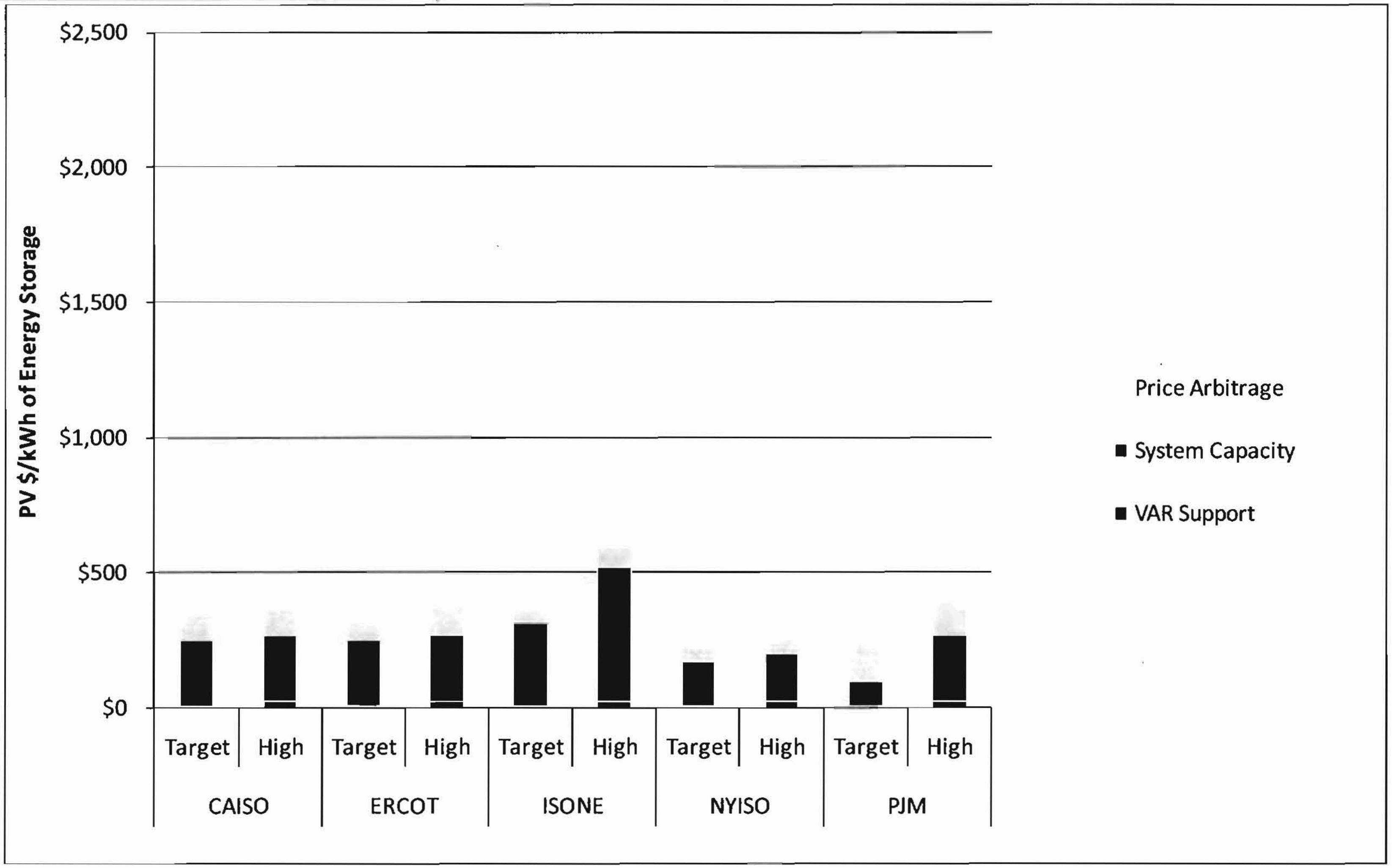
Levelized Cost of Delivered Energy for Energy Storage Technologies



See: EPRI 1020676

Application, Whole Sale Energy Services Value based on Benefit Revenue Mechanisms



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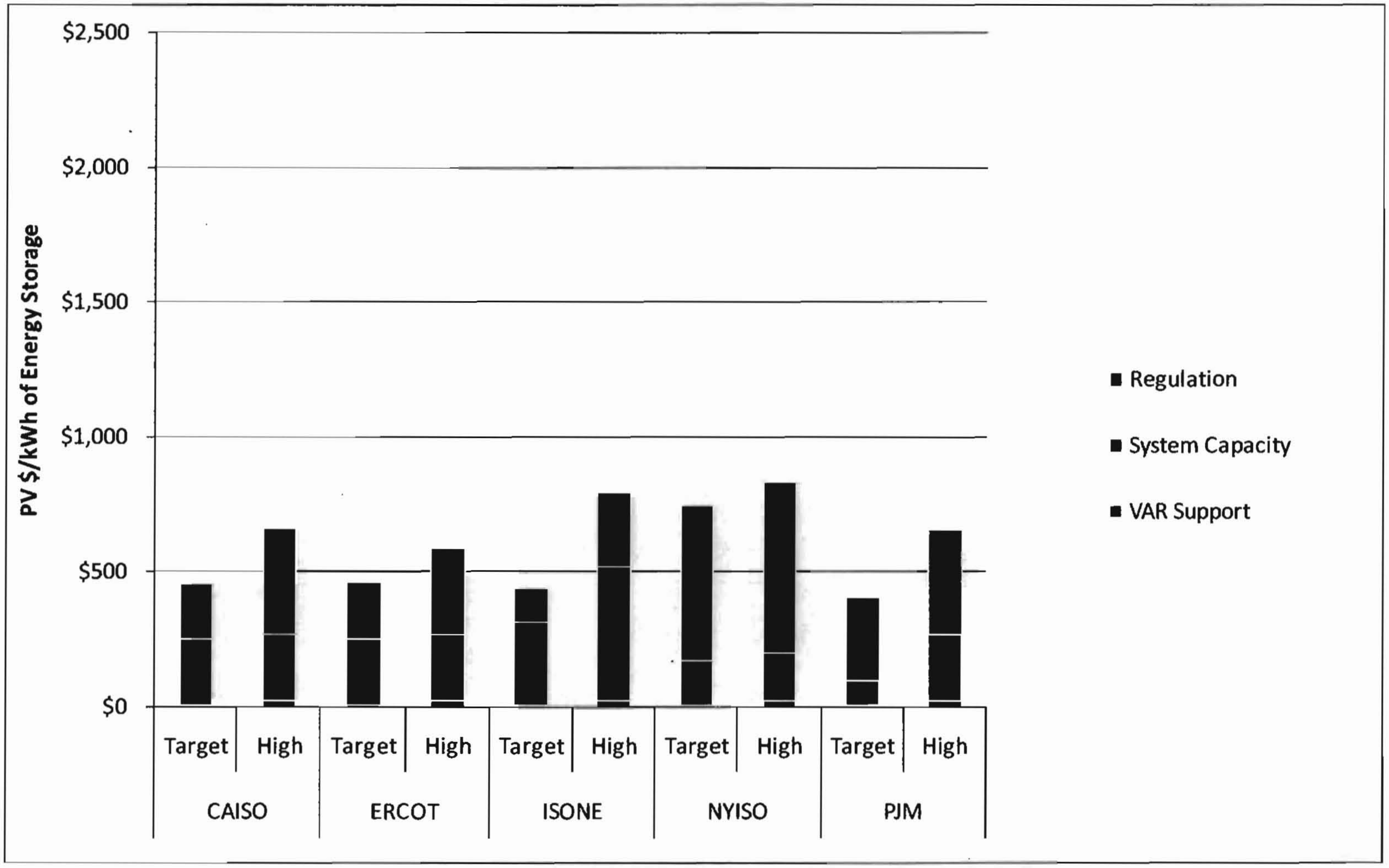
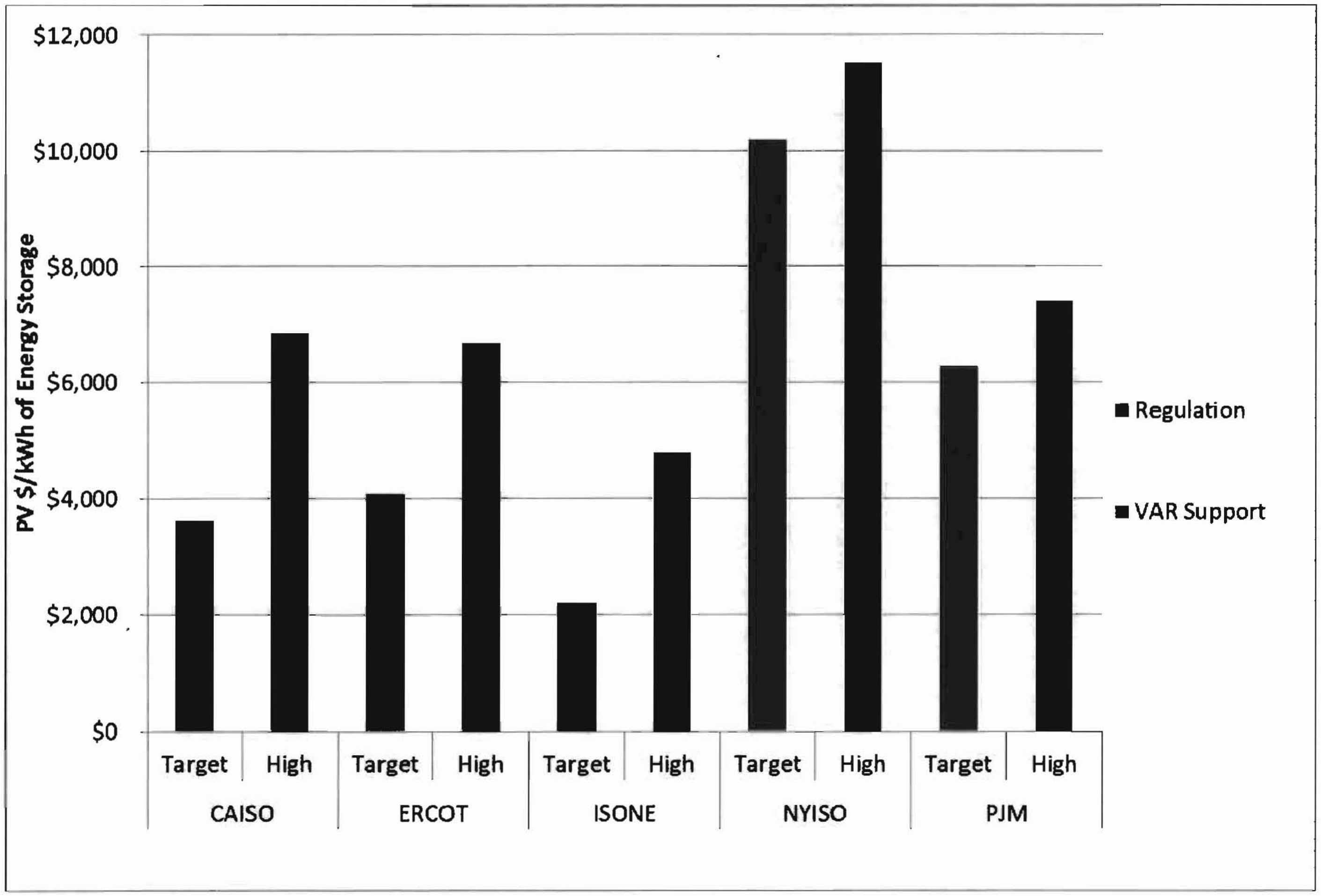
Application, Whole Sale Energy Services



Application: Wholesale Services – 15 Min. Regulation



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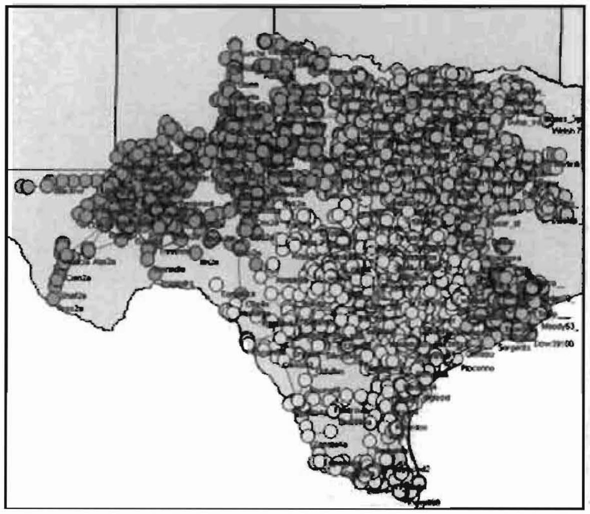
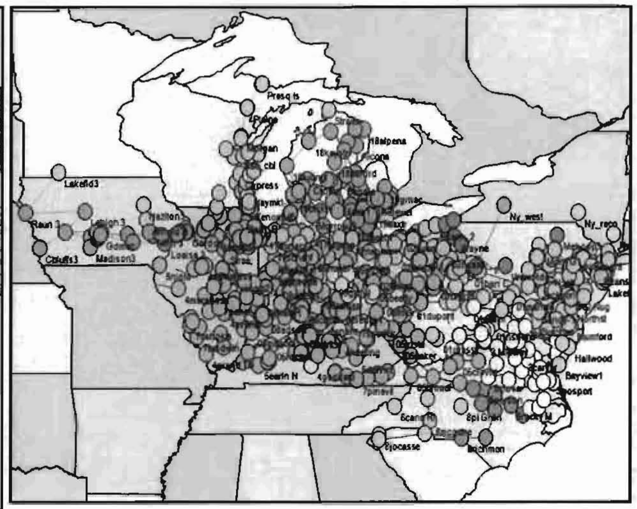
Economic and Societal value of Storage for Wind Integration,Benefits, and Revenue Streams

Simulations of Storage Systems in ERCOT, PJM and NYISO

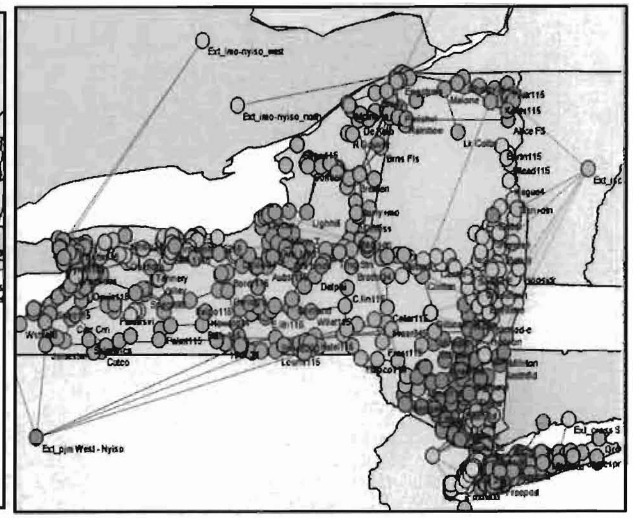
ERCOT



PJM & Eastern Interconnect



NYISO



Study Year 2015	Study Year: 2015	Study Year: 2013
CREZ 2 Scenario $ 4.9 B in new Transmission Wind Additions: 18 GW	Demand / Generation Mix Transmission Topology Commodity Prices Wind Additions: 12.8 GW	Demand / Generation Mix Transmission Topology Commodity Prices Wind Additions: 4.2 GW

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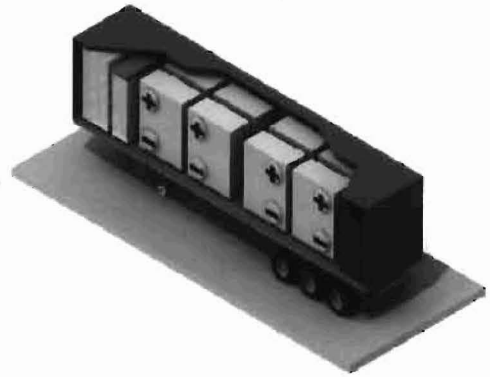
Conduct Simulations of Storage Portfolios in CA

Example: Assess R&D of Energy Storage Portfolios



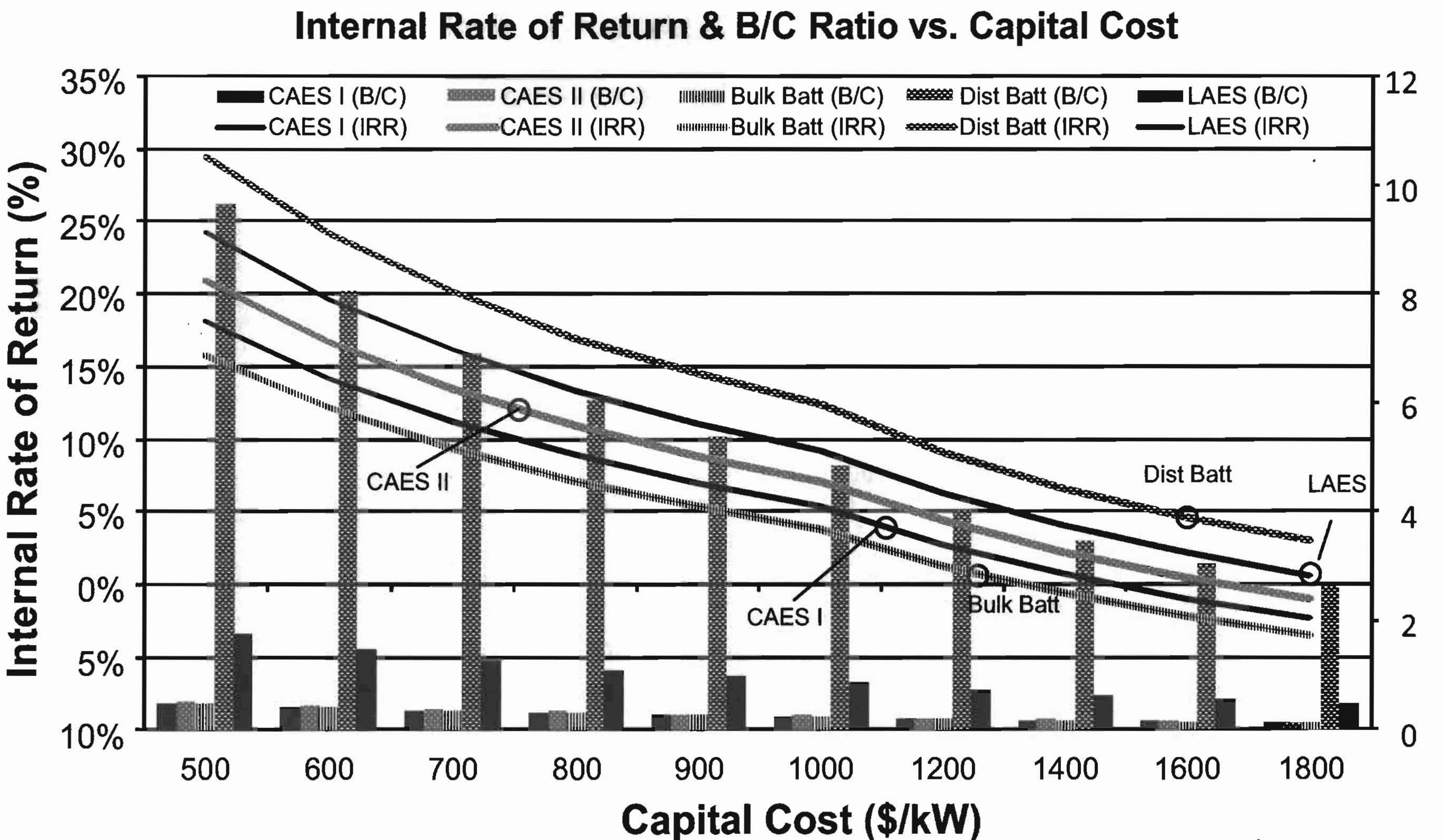
Compressed Air Energy Storage	Bulk Battery System	Distributed Battery
400 MW 20-30 hrs 3950 Btu kWh* 0.75 Energy Ratio $ 700 - $ 1000 / kW	100 MW x 4 6 hrs 80% ac-ac eff. $ 1200-$1500/kW	1 MW x 400 2 hrs 85% ac-ac eff. $ 1200-$1500/ kW

The study objective was to understand and estimate the role and impacts of various energy storage options under the assumed wind penetration and grid network configuration

* A non-fuel CAES cycle was also analyzed

Example Regional Case Study –ERCOT 2015

Results are dependent on Location, Commodity Prices, Generation Mix, Wind Penetration and Grid Topology



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Example Regional Case Study –ERCOT 2015

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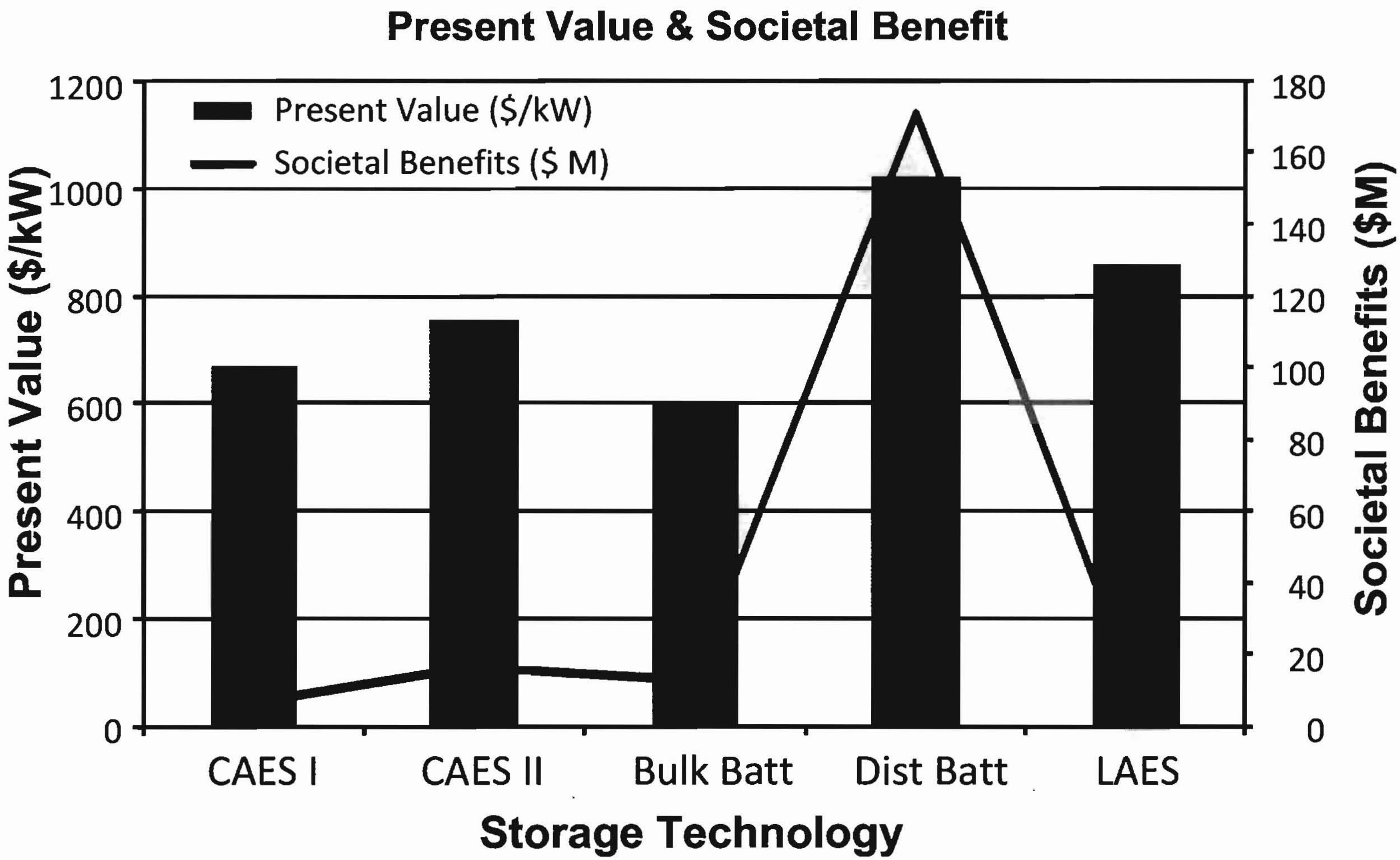

Recommendations: Conduct Detailed Statewide Modeling and Simulations to Assess Economic Value and Impact of Energy Storage Options

- Criteria for evaluating the efficacy of the storage should be based on
  - System Benefits/Costs,
  - Producers and consumers benefits,
  - Societal benefits, Congestion mitigation, GHG impact,
  - Congestion management,
  - Operational impact on other generators

Note: ERRI Plans to Conduct Limited Simulations in CA in 2011

Recommendations for CA

Top Down and Bottom Up Market Assessments Needed

Energy Storage to Support Wind Integration (Top Down)

- Conduct Integrated California Market and Grid Simulations (Supply, T&D, Demand) under RPS to better define the Role, Location, Optimal Mix of Storage Options which can contribute to CA Policy Goals;
- Use above Analytics to establish a Road Map and Application / Solution (s) for CA which are cost effective and achieve desired impacts;
- Define Functional Requirements and Technically Specify Storage Solutions / Requirements

Energy Storage to support Load Serving Entities and Communities

- LSE's near and long-term planning to investigate use of storage as part of Smart Grid; Distribution infrastructure support; end-use peak mgt.
- Distribution and Smart Grid Planning Efforts
- Analysis to assess impacts and operational value
- Analysis of benefits and costs to support business case
- Policy to accommodate cost recovery and alternative business models

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