



Energy Storage Valuation Tool Draft Results

Investigation of Cost-Effectiveness Potential for Select CPUC Inputs and Storage Use Cases in 2015 and 2020

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EPRI Energy Storage Program

CPUC Storage OIR Workshop (R.10-12-007)

3-25-13





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Garage – An Asset Utilization Case Study



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w Industries are Emerging to Address Low set Utilization

- Underutilized assets leave a lot of money on the table
- Improved communication and information has lowered transaction costs and enabled new markets



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Baky Loads Cause Utilization Issues for ectric Systems

- Not just generation, but the entire T&D delivery system
- Storage could shift load from off-peak to on-peak load periods to avoid additional peak generation and T&D delivery system Illustration Only



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Bergy Storage Can Help

- Not just generation, but the entire T&D delivery system
- Storage could shift load from off-peak to on-peak load periods to avoid additional peak generation and T&D delivery system Illustration Only



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Bottle Opener – An Elegant Tool

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e Bottle Opener - Alternatives exist, but they e less well-suited



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equency Regulation – A niche, challenging rvice for conventional grid assets



Slow Ramping of Conventional Generator



Flywheel / Battery Energy Storage Example

Sources Kirby, B. "Ancillary Services: Technical and Commercial Insights." Wartsilla, July, 2007. pg. 13

- Fossil generator has slower response and ramp than required, and has opportunity cost of lost energy sales
- Storage can provide not only its generating capacity, but also its load to balance the system ۲ frequency
- FERC755 (Regulation Pay-for-performance) is planned for implementation in 2013 and may increase current CAISO Regulation prices when implemented



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orage value lies where it has a strong mpetitive advantage vs. conventional assets

- Use charging and discharging to simultaneously address both under (off-peak) and over-utilization (peak) of grid assets (T&D deferral & System capacity)
- Create value for storage charging, speed, and accuracy (Regulation)



Value for energy time-shift (arbitrage) is comparatively low

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day's Proposed Agenda

- Introduction to EPRI
- Background
- Analytical Process
- Discussion Break
- Model
- Input Discussion Preface
- Performed Use Case Inputs and Results
 - #1: Bulk Storage (Peaker Substitution)
 - #2: Ancillary Services (Regulation) only
- Discussion Break / Lunch
- Performed Use Case Inputs and Results
 - #3: Distributed Storage sited at Utility Substation

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- Conclusions & Next Steps
- Discussion

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EPRI Introduction

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e Electric Power Research Institute (EPRI)

- Independent, non-profit, collaborative research institute, with full spectrum industry coverage
 - Nuclear
 - Generation
 - Power Delivery & Utilization
 - Environment & Renewables
- Major offices in Palo Alto, CA; Charlotte, NC; and Knoxville, TN



Technically informing regulatory / policy-makers fits within EPRI's m

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RI Energy Storage Program Mission

- Facilitate the development and implementation of storage options for the grid.
 - Understanding storage technologies
 - Identifying and calculating the impacts and value of storage
 - Specification and testing of storage products
 - Implementation and deployment of storage systems

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Sourage costs are falling with manufacturing investment



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Ceating a Complete Storage Product



Storage Technologies

- Define duty cycle and expectations for life and efficiency
- Characterize performance
 in different regimes

Power Conditioning System

- Define critical functions and performance levels
- Test capabilities to understand optimal performance

Product Integration

- Guidelines for integration of components to ensure proper performance
- Test and evaluate product as a whole

Acquiring complete, working systems has been the most challenging part of energy storage efforts to date

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id Deployment and Integration



Field Deployment

- Installation, operations, and ٠ disposal best practices
- Siting and permitting issues ٠
- Safety and emergency protocols



Grid Integration

- Physical interconnection and protection protocols
- Methods for • understanding the effects on the distribution system



Control and Dispatch

- Communication and control protocol
- SGIP and cybersecurity •
- **Developing optimal** dispatch algorithms

Interconnection of storage to the grid is still relatively poorly understood

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Encus for Today's Presentation

- There are many areas of ongoing research to enable gridready energy storage
- Today we are discussing one part: storage value analysis (under specific assumptions)



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Background / Analytical Process

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Content of this Analytical Process





erview of EPRI Storage Cost-Effectiveness thodology



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RI Storage Cost-Effectiveness Methodology



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RI Storage Cost-Effectiveness Methodology

Step 1a: Grid Problem / Solution Concepts

Step 1b: Grid Service Requirements

Define quantifiable services storage can provide

Step 2: Feasible Use Cases

Focus of this Analysis

Not Included in Today's Analysis

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Conversion of Step 2: Feasible Use Cases

- Simulate energy storage use case operation to address multiple grid services with quantifiable technical requirements and benefits
 - Prioritize serving long-term commitments (e.g. multi-year asset deferral over a day-ahead market opportunity)
 - Constrain operation by storage technical limitations
 - Co-optimize dispatch in the markets to maximize benefits
- Total Resource Cost (TRC) test approach focus on aggregate ("stacked") value, ignore stakeholders & transaction costs
 - Ignore bulk system and environmental impacts
 - Ignore policy incentives and monetization restrictions

Understand which use case assumptions (technology, site, etc. may make storage cost-effective, and which inputs are impo

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UC Use Cases

Use Cases	Categories	
	Bulk Storage System	
Transmission-Connected Energy Storage	Ancillary Services	
	On-Site Generation Storage	
	On-Site Variable Energy Resource Storage	
Distribution-Level Energy Storage	Distributed Peaker	
	Distributed Storage Sited at Utility Substation	
	Community Energy Storage	
Demand-Side (Customer-Sited) Energy Storage	Customer Bill Management	
	Customer Bill Management w/ Market	
	Participation	
	Behind the Meter Utility Controlled	
	Permanent Load Shifting	
	EV Charging	

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CPUC Use Cases Investigated in the Analysis

Use Cases	Categories	
	Bulk Storage System (aka Peaker Subsitution)	
Transmission-Connected Energy Storage	Ancillary Services	\square
	On-Site Generation Storage	
	On-Site Variable Energy Resource Storage	
Distribution-Loval	Distributed Peaker	
Distribution-Level	Distributed Storage Sited at Utility Substation	X
Energy Storage	Community Energy Storage	
	Customer Bill Management	
	Customer Bill Management w/ Market	
Demand-Side (Customer-Sited) Energy Storage	Participation	
	Behind the Meter Utility Controlled	
	Permanent Load Shifting	
	EV Charging	

Focus limited due to project resource constraints

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Cases Defined by Quantifiable Grid rvices Addressed

		\mathbf{X}	X	\mathbf{X}
Category	Quantifiable Grid Services	ces CPUC Use Cases Incl. in Analysis		
		Bulk-"Peaker Sub"	Ancillary Services	Dist. Sub. Storage
Energy	Electric Supply Capacity	X		X
	Electric Energy Time-Shift	Х		X
A/S	Frequency Regulation	X		Х
	Spinning Reserve	Х		X
	Non-Spinning Reserve	X		X
Transmission	Transmission Upgrade Deferral			
	Transmission Voltage Support			
Distribution	Distribution Upgrade Deferral			X
	Distribution Voltage Support			
Customer	Power Quality			
	Power Reliability			
	Retail Demand Charge Mgmt			
	Retail Energy Time-Shift			

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Other services and benefits may exist -

but they may be indirect or difficult to quantify

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Discussion Break

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hat is the Energy Storage Valuation Tool SVT) ?

Transparent, user-friendly, CBA tool to assess and communicate energy storage cost-effectiveness in different use cases

- Customizable storage project lifecycle financial analysis
- Includes pre-loaded defaults for energy storage service requirements, prioritization, values, storage technologies
- Simulates use case cost-effectiveness with Total Resource Cost (TRC) approach (stacks benefits across stakeholders)
- **Multi-stakeholder** services/benefits: Generation, Transmission, Distribution, Customer
- Transparent model approach with Analytica[™] software model / input transparency through influence diagrams

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hat is the Energy Storage Valuation Tool 5VT) ?

Transparent, user-friendly, CBA tool to assess and communicate energy storage cost-effectiveness in different use cases

EPRI RECEIPTION ENDINE Energy Storage Valuation Tool 3.1				
Step 1: Select Grid Services for Analysis	Enable Optimization Yes V			
ISO/RTO/Service Area CAISO: 2011 V	Services Selection			
Step 1b. : Define Grid Service Requirements				
System Market Inputs Transmission Inputs	Distribution Inputs Customer Premise Inputs			
tep 2: Select Financial and Economic Assun	nptions			
Ownership type				
Discount Rate Calc md	Financial and Economic Inputs			
tep 3: Select Energy Storage System Perfor	mance Characteristics and Costs			
Technology Li-Ion: 1 MW/4 Hour	Discharge Duration (Hours) 4 mil			
Discharge Capacity (KW) 1000 mil	Storage System Capital Costs (\$) \$3,600,000 md			
Define Custom Storage System (Optional)	Storage System Capital Co. (\$/kW) \$3,600 met			
tep 4: Calculate Results Calc All				
NPV Cost vs. Benefit Catc	Daily Revenue (\$) Calc not			
Annual Services Revenue (\$) Calc ma	Daily Dispatch (kWh) Calc mid			
Financial Results Technical Results	Service Specific Results Model Details			

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Instration of ESVT Operation

INPUTS

MODEL

OUTPUTS

NPV Cost / Benefit

Prices / Loads



Financial Assumptions



Storage Cost / Performance



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Storage Priority / Bid / Dispatch









rengths and Current Limitations of ESVT

- Strengths
 - Quick to setup and run analyses dozens of input parameters, not hundreds
 - Simulates storage optimal dispatch provides insights into cost-effective use cases and relative importance of inputs
 - Designed specifically to incorporate storage cost / performance parameters
- Limitations
 - No system price or generators impacts measured does not simulate the effects of different storage deployment levels
 - No consideration of environmental / GHG impacts

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Discussion of Inputs to CPUC Analysis

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New of Analysis Inputs Process


view of Analysis Inputs Process

- December 2012 Discussion of Use Cases for Initial Focus
 - Bulk Peaker Substitution, A/S only
 - Distribution Substation-sited
- Jan-Feb 2013 CPUC request of 50 runs (prioritized)
- Jan-Mar 2013 Weekly input clarification meetings with CPUC and 2 preliminary analysis results with stakeholder group
- March 2013 Approximately 30 runs performed (time/budget constraints) with selected additional sensitivities

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Cverview of Input Worksheet provided by CPUC

• File: "Storage CE Input Template V12"



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erview of Results Worksheet provided by RI

• File: "ESVT Results for CPUC workshop_draft_3-25-13"

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Status Run	Broakeven B/C Capital Cost Ratio (S/kwh)*	Breakeven t Capital Cost (S/kW)*	Breakeven Capital Cost (\$/kWh) (2013\$)**	Breakeven Capital Cost (S/kw) (20135)**	Project Start Year	Une Cane	Technology	Nameplat Capacity (MW)	Storage Duration (h)	Totař Capex (S/kw)	Total Capes (5/kw) in 2013	Replacement Cost (S/kwb)	Replacement Cost of New Cost 2013 Entry (CONE)	De Ca (M
Done runid Done runie	1.34 83 0.96 42	07 1674 10 840	729 366		1457 731		Battery Battery		2	1056 1056	919 919	250 250	218 E3 DER ACM 218 E3 DER ACM	E
eference"	1.38 182 1.10 66 1.03 52	0 3040 9 2007 11 2004	1304 		3169 1747 1814		Battery Battery Battery			1056 1406 1761	919 1224 1533	250 250 250	218/03 DER ACM 218/03 DER ACM 218/03 DER ACM	
Summary	0.99 N/ 0.32 N/ 1.21 106	A 0 A 0 0 2120	Indivic	lual Run I	Resu	llts; Ru	ns with		2 N/A N/A	1619 1535 1556	1409 1336 919	N/A N/A 250	N/A ESVT Derived N/A E3 DER ACM 218 ESVT Derived	
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* ** Reference, cuil o	1.80 1.80 1.30 0015 Putrist - Putrist	NIC AVAID	nanie "marg "nani	and the second second	NU-2 - 1011	6 Arry rante	nell, nell, ne	ni3 net4	10.13	1206	11599 1972 1972	÷}	240 E3 DER ACM 240 E3 DER ACM 240 E3 DER ACM	ţ.

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Use Case #1: Bulk Storage (Peaker **Substitution) Inputs and Results**

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Meminder – 3 CPUC Use Cases

		\bigstar		\bigstar
Category	Quantifiable Grid Services	CPUC	Use Cases Incl. in An	alysis
		Bulk-"Peaker Sub"	Ancillary Services	Dist. Sub. Storage
Eporgy	Electric Supply Capacity	X		\mathbf{X}
Energy	Electric Energy Time-Shift	X		X
	Frequency Regulation	X	X	X
A/S	Spinning Reserve	X		X
	Non-Spinning Reserve	X		X
Transmission	Transmission Upgrade Deferral			
	Transmission Voltage Support			
Distribution	Distribution Upgrade Deferral			X
Distribution	Distribution Voltage Support			
	Power Quality			
Customor	Power Reliability			
customer	Retail Demand Charge Mgmt			
	Retail Energy Time-Shift			

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EIk Storage Peaker Substitution

		\star	
Category	Quantifiable Grid Services	CPUC U	lse Cases Incl. in Analysis
		Bulk-"Peaker Sub"	·
Enormy	Electric Supply Capacity	X	1.Electric Supply
Energy	Electric Energy Time-Shift	X	Capacity
	Frequency Regulation	×	
A/S	Spinning Reserve	X	2.Electric Energy
	Non-Spinning Reserve	X	Time Shift
Transmission	Transmission Upgrade Deferral		2 -
	Transmission Voltage Support		3.Frequency
Distribution	Distribution Upgrade Deferral		Regulation
Distribution	Distribution Voltage Support		
	Power Quality		4.Spinning Reserve
Customer	Power Reliability		5 Non-Spinning
	Retail Demand Charge Mgmt		
	Retail Energy Time-Shift		Keserve

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orage Dispatch Modeling Approach for Peaker Ibstitution Use Case

 Reserve top 20 CAISO load hours per month for providing energy to earn system capacity value

 Co-optimize for profitability between energy and ancillary services (reg up, reg down, spin, non-spin)



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fore calculating storage cost effectiveness...

- · We need a method for determining system capacity value
- System capacity value is determined by a metric called Cost of New Entry (CONE)
- CONE is the minimum required system capacity annual payment to build a new marginal combustion turbine(CT) – in California, LM6000 w/ SPRINT
- · CONE was calculated two ways:
 - E3 DER Avoided Cost Calculator* (base)
 - ESVT Residual capacity value calc



* http://www.ethree.com/documents/DERAvoidedCostModel v3 9 2011 v4d.xlsm

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stem Capacity Revenue for Storage



CONE = \$155/kW-yr (Derived from E3 DER avoided cost model)

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riving and Comparing CONE values for stem Capacity Value



Ik – Peaker Substitution Use Case Base Case sumptions Provided by CPUC

Key Global and System / Market Assumptions

Category	Input	2020	2015
	Financial Model	IPP	IPP
Global	Discount Rate	11.47%	11.47%
	Inflation Rate	2%	2%
	Fed Taxes	35%	35%
	State Taxes	8.84%	8.84%
	Base Year Reference	CAISO 2011	CAISO 2011
	Real Fuel Escalation Rate	2%	2%
	Energy & A/S Escalation Rate	3%	3%
	Yr 1 capacity value (\$/kW-yr)	\$155	\$72
	CONE value (\$/kW-yr)	\$155	\$155
System / Market	Resource Balance Year	2020	2020
	Mean Energy Price (\$/MWh)	39.96	34.47
	Mean Reg Up Price (\$/MW-hr)	12.01	10.36
	Mean Reg Down price (\$/MW-hr)	9.04	7.80
	Mean Spin price (\$/MW-hr)	9.43	8.13
	Mean Non-Spin price (\$/MW-hr)	1.28	1.11

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Ik – Peaker Substitution Base Case sumptions Provided by CPUC

 Key technology cost / performance assumptions – storage and conventional (CT)

Category	Input	2020				2015		
		Battery*	Flow Battery	PHS	AG CAES	CT**	Battery	Flow Battery
	Nameplate Capacity (MW)	50	50	300	100	50	50	50
	Nameplate Duration (hr)	2	4	8	8	-	2	4
	Capital Cost (\$/kWh) -Start Yr Nominal	528	443	166	211	-	603	775
	Capital Cost (\$/kW) - Start Yr Nominal	1056	1772	1325	1684	1619	1206	3100
	Project Life (yr)	20	20	100	35	20	20	17
	Roundtrip Efficiency	83%	75%	82.50%	-	-	83%	70%
	Variable O&M (\$/kWh)	0.00025	0.00025	0.001	0.003	0.004	0.00025	0.00025
Technology Cost /	Fixed O&M (\$/kW-yr)	15	15	7.5	5	17.4	15	15
Performance	Major Replacement Frequency	1	0	-	-	-	1	0
	Major Replacement Cost (\$/kWh)	250	-	-	-	-	250	-
	MACRS Depreciation Term (yr)	7	7	7	7	7	7	7
	Energy Charge Ratio (CAES)	-	-	-	0.7	-	-	-
	Full Capacity Heat Rate (CAES/CT)	-			3810	9387	-	-
	Heat Rate Curve (CAES/CT)	-	-	-	see wkst	see wkst	-	-
	Turbine Efficiency Curve (PHS)	-	-	see wkst	-	-	-	-
	Pump Efficiency (PHS)	-	-	see wkst	-	-	-	

Battery based loosely on Li-ion is most common base case * **CT based on LM6000 w/ SPRINT technology

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In 1: Peaker Substitution Result for Base Case th CPUC Inputs

- Benefit/Cost Ratio = 1.17 ۲
- Breakeven Capital Cost: \$831/kWh (\$1662/kW) in 2013 inflation adjusted dollars



2020 Base Case

- Synchronous Reserve
- Non-synchronous Reserve
- System Electric Supply
- Electricity Sales
- Taxes (Refund or Paid)
- Operating Costs
- Financing Costs (Debt)
- Capital Expenditure



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Year 2020

\$250/kWh

Sensitivity to Regulation Service Value (1 of 2) **Regulation Price vs. 2X Price**

			Base Case	Ba Re	ase Caso eg	e + 2x
Breakeven Capital C	ost in 2	013 dollars	\$831/kWh (\$1662/kW)	\$´ (\$	1584 /kW 3168/kW	′h ′)
	" 300	20	20 Base Case		Base (Reg	Case + 2x g price
<u>Base Case Inputs</u> Year 2020	sio IIIIN 250		 ■ Frequency Regulation ■ Synchronous Reserve (Spin) 	300 signal	Mu	ltiplier
50MW, 2hr (battery) CapEx = \$1056/kW, \$528/kWh	200		Non-synchronous Reserve (Non-spin)	₩ 250)		
1 Batt Replacement @ \$250/kWh 11 5% discount rate	150		 System Electric Supply Capacity Electricity Sales 	200		
83% RT Efficiency Energy & A/S prices escalated 3%/yr from CAISO 2011	100		■ Taxes (Refund or Paid) ■ Operating Costs	100 -		
	50		—— ■ Financing Costs (Debt) ■ Capital Expenditure	50		
	0	Cost Ber	nefit (Equity)		Cost	Benefit

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Sensitivity to Regulation Service Value (2 of 2) se Regulation Value vs. No Regulation Value

			Bas	e Case	Ba Re	ase Case egulation	w/o
Breakeven Capital C	cost in 2	013 dollars	\$83 (\$10	1 /kWh 662/kW)	\$4 (\$	23 /kWh 846/kW)	
	300	20)20 B	ase Case	B	ase Case Regulati	e w/o ion
	lions			Frequency Regulation	<mark>ي</mark> 300		
Pase Case Inputs Year 2020	₩ ₂₅₀			⊂ ■Synchronous Reserve (Spin)	VIIII 250		
50MW, 2hr (battery)				Non-synchronous			
CapEx = \$1056/kW, \$528/kWh 1 Batt Replacement @ \$250/kWh	200			System Electric Supply Capacity	200		
11.5% discount rate	150			Electricity Sales	150		
83% RT Efficiency Energy & A/S prices escalated	100	-		■ Taxes (Refund or Paid)	100		
3%/yr from CAISO 2011				Operating Costs			
	50			Financing Costs (Debt)	50		
	0	Cost Be	enefit	Capital Expenditure (Equity)	0	Cost	Benefit
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se Case (2hr) vs. 3hr vs. 4hr

	Base Case	Duration 3hr	Duration 4hr
Breakeven Capital Cost in	\$831 /kWh	\$582 /kWh	\$454 /kWh
2013 dollars	(\$1662/kW)	(\$1746/kW)	(\$1816/kW)

2020 Base Case (2hr Duration) Frequency Regulation Synchronous Reserve (Spin)

Benefit



Supply Capacity Electricity Sales

■Taxes (Refund or Paid)

Operating Costs

- Financing Costs (Debt)
- Capital Expenditure (Equity)



Base Case + 4hr Duration



Base Case Inputs

300

250

200

150

100

50

0

Millions

Year 2020; 50MW, 2hr (battery); CapEx = \$1056/kW, \$528/kWh; 1 Batt Replacement @ \$250/kWh; 11.5% discount rate; 83% RT Efficiency; Energy & A/S prices escalated 3%/yr from CAISO 2011

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Cost



sensitivity to Battery Replacement Frequency*



Base Case Inputs

Year 2020; 50MW, 2hr (battery); CapEx = \$1056/kW, \$528/kWh; Batt Replacements @ \$250/kWh; Battery replacements equally spaced over 20 yr life; 11.5% discount rate; 83% RT Efficiency; Energy & A/S prices escalated 3%/yr from CAISO 2011 © 2013 Electric Power Research Institute, Inc. All rights reserved. 53

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Sensitivity to Project Start Year: 2020 vs. 2015



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Cher Technology Comparison (Flow Battery, **ES**, Pumped Hydro)

				Flow Battery		Pumpeo Hydro	1	Abv G CAES	roun	d
Breakeven Ca 2013 dollars	pita	l Cost i	1	\$664/kWh (\$2657/kW)		\$214/kW (\$1713/ł	Vh «VV)	\$224/k (\$1790	.Wh)/kW)	
Global Inputs						Pumn	ed	Δ	G CA	FS
11.5% discount rate		Flo	w B	attery	4 000			~		
Energy & A/S prices escalated 3%/yr from CAISO 2011	300				1,200	- Tyu	0	500 SUO 450		
Flow Battery Inputs	250		8	Frequency Regulation	1,000					
50MW, 4hr (battery)	200		1	Synchronous Reserve				400		-
CapEx = \$1772/kW			10000	(Spin) Non-svnchronous	800			350		_
75% RT Efficiency	200			Reserve (Non-spin)	800			300		
No battery replacements				System Electric				000		
PH Inputs	150		-	Electricity Sales	600			250		
300MW, 8hr				Taxes (Refund or			NAMES OF COMPANY	200		
\$1325/kW, 100 yr project life	100			Paid)	400			150		-
VO&M = \$1.02/MWh, FO&M = \$7.5/kW-yr	50		I	 Operating Costs Financing Costs 	200			100		
CAES Inputs				(Debt)	200			50		
100MW, 8h	0			Capital Expenditure	-			0		
\$1584/kW, 35 yr life	Ŭ	Cost Ber	efit	(0	Cost	Benefit	. 0	Cost	Benef
Energy charge ratio = 0.7						0000	Donom			
Full load heat rate = 3810 © 2013 Electric Power Research Institut	e, Inc. All	rights reserved.		55				EP		ECTRIC PO

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erview of Bulk / Peaker Results in ESVT eakeven Capital Costs (CPUC Inputs)



** "Current costs" applicable to 2-4hr battery, not other technologies contained

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mmary of B/C ratio results for Bulk Storage (eaker Sub) – CPUC Inputs / Costs

B/C Ratio



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Use Case #2: A/S (Regulation)-only **Inputs & Results**

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Meminder – 3 CPUC Use Cases

		\bigstar	\bigstar	\bigstar
Category	Quantifiable Grid Services	CPUC	Use Cases Incl. in Ar	alysis
		Bulk-"Peaker Sub"	Ancillary Services	Dist. Sub. Storage
Enormy	Electric Supply Capacity	X		X
Епегду	Electric Energy Time-Shift	X		X
A/S	Frequency Regulation	X	X	X
	Spinning Reserve	X		X
	Non-Spinning Reserve	X		X
Transmission	Transmission Upgrade Deferral			
	Transmission Voltage Support			
Distribution	Distribution Upgrade Deferral			X
	Distribution Voltage Support			
	Power Quality			
Customor	Power Reliability			
customer	Retail Demand Charge Mgmt			
	Retail Energy Time-Shift			

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K6 (Regulation)-Only

Category	Quantifiable Grid Services	CPUC Use Cases Incl. in An	alysis
		Ancillary Services	
Enormy	Electric Supply Capacity		
Lifeigy	Electric Energy Time-Shift		
	Frequency Regulation	X	
A/S	Spinning Reserve		
	Non-Spinning Reserve		1.Frequency
Transmission	Transmission Upgrade Deferral		Regulation
1141151111551011	Transmission Voltage Support		g
Distribution	Distribution Upgrade Deferral		
Distribution	Distribution Voltage Support		
	Power Quality		
Customore	Power Reliability		
customer	Retail Demand Charge Mgmt		
	Retail Energy Time-Shift		

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orage Dispatch Modeling Approach for gulation Only Use Case

- Optimize for profitability between regulation up, regulation down, and no action; manage storage state-of-charge
- Account for associated charging / discharging costs and revenues



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6 (Regulation)-only Base Case Assumptions bvided by CPUC (1 case)

Key Global and System / Market Assumptions

Category	Input	2020
	Financial Model	IPP
	Discount Rate	11.47%
Global	Inflation Rate	2%
	Fed Taxes	35%
	State Taxes	8.84%
	Base Year Reference	CAISO 2011
	Real Fuel Escalation Rate	2%
Suctor / Market	Energy & A/S Escalation Rate	3%
System / Warket	Mean Energy Price (\$/MWh)	39.96
	Mean Reg Up Price (\$/MW-hr)	12.01
	Mean Reg Down Price (\$/MW-hr)	9.04

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6 (Regulation)-only Base Case Assumptions ovided by CPUC (1 case)

Key technology cost / performance assumptions

Category	Input	2020
		Battery
Technology Cost / Performance	Nameplate Capacity (MW)	20
	Nameplate Duration (hr)	0.25
	Capital Cost (\$/kWh) -Start Yr Nominal	3112
	Capital Cost (\$/kW) - Start Yr Nominal	778
	Project Life (yr)	20
	Roundtrip Efficiency	83%
	Variable O&M (\$/kWh)	0.00025
	Fixed O&M (\$/kW-yr)	15
	Major Replacement Frequency	1
	Major Replacement Cost (\$/kWh)	250
	MACRS Depreciation Term (yr)	7

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Segulation Only Result (2x Regulation Price



	B/C Ratio	1.40
	Breakeven Capital Cost in 2013 dollars	\$1678/kW (\$6712/kWh)
gulation		
s		
l or Paid)		
ts		
ts (Debt)		
diture		

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Discussion Break / Lunch

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Use Case #3: Distribution Storage at Substation Inputs & Results

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Meminder – 3 CPUC Use Cases

		\bigstar		\bigstar	
Category	Quantifiable Grid Services	CPUC Use Cases Incl. in Analysis			
		Bulk-"Peaker Sub"	Ancillary Services	Dist. Sub. Storage	
Energy	Electric Supply Capacity	X		X	
	Electric Energy Time-Shift	Х		X	
	Frequency Regulation	X	X	X	
A/S	Spinning Reserve	X		X	
	Non-Spinning Reserve	X		X	
Transmission	Transmission Upgrade Deferral				
Tansmission	Transmission Voltage Support				
Distribution	Distribution Upgrade Deferral			X	
Distribution	Distribution Voltage Support				
Customer	Power Quality				
	Power Reliability				
	Retail Demand Charge Mgmt				
	Retail Energy Time-Shift				

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Stribution Storage at Substation

			\star
Category	Quantifiable Grid Services	CPUC Use Cases Incl. in Analysis	
			Dist. Sub. Storage
Eporav	Electric Supply Capacity		X
Litergy	Electric Energy Time-Shift	1.Electric Supply Capacity	X
A/S	Frequency Regulation	2.Electric Energy Time Shift	X
	Spinning Reserve	2 Eroqueney Degulation	X
	Non-Spinning Reserve		X
Transmission	Transmission Upgrade Deferral	4.Spinning Reserve	
110113111331011	Transmission Voltage Support	5 Non-Spinning Reserve	
Dictribution	Distribution Upgrade Deferral		X
Distribution	Distribution Voltage Support	6. Distribution Upgrade	
Customer	Power Quality	Deferral	
	Power Reliability		
	Retail Demand Charge Mgmt]	
	Retail Energy Time-Shift		

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brage Dispatch Modeling Approach for stribution Storage at Substation Use Case

 Top priority: Peak shave annual peak distribution load to offset load growth and defer upgrade investment for years

Second priority: Reserve Top

for providing energy



 Co-optimize for profitability between energy and ancillary services (reg up, reg down, spin, non-spin)



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Stributed Storage at Substation Base Case sumptions Provided by CPUC

Key Global and System / Market Assumptions

Category	Input	2020	2015
	Financial Model	IPP	IPP
	Discount Rate	11.47%	11.47%
Global	Inflation Rate	2%	2%
	Fed Taxes	35%	35%
	State Taxes	8.84%	8.84%
	Base Year Reference	CAISO 2011	CAISO 2011
	Real Fuel Escalation Rate	2%	2%
	Energy & A/S Escalation Rate	3%	3%
	Cost of Distribution Upgrade (\$/kW)	\$309	\$279
	Feeder Type	C&I	C&I
	Load Growth Rate	2%	2%
Suctors / Market	Yr 1 capacity value (\$/kW-yr)	\$155	\$72
System / Warket	CONE value (\$/kW-yr)	\$155	\$155
	Resource Balance Year	2020	2020
	Mean Energy Price (\$/MWh)	39.96	34.47
	Mean Reg Up Price (\$/MW-hr)	12.01	10.36
	Mean Reg Down Price (\$/MW-hr)	9.04	7.80
	Mean Spin Price (\$/MW-hr)	9.43	8.13
	Mean Non-Spin Price (\$/MW-hr)	1.28	1.11

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Stributed Storage at Substation Base Case sumptions Provided by CPUC

Key technology cost / performance assumptions

Category	Input	2020		2015
		Battery (4hr)	Battery (4hr)	Flow Battery (4hr)
	Nameplate Capacity (MW)	1	1	1
	Nameplate Duration (hr)	4	4	4
	Capital Cost (\$/kWh) -Start Yr Nominal	437	500	775
Гесhnology Cost / Performance	Capital Cost (\$/kW) - Start Yr Nominal	1750	2000	3100
	Project Life (yr)	20	20	17
	Roundtrip Efficiency	83%	83%	70%
	Variable O&M (\$/kWh)	0.00025	0.00025	0.00025
	Fixed O&M (\$/kW-yr)	15	15	15
	Major Replacement Frequency	1	1	0
	Maj o r Replacement Cost (\$/kWh)	250	250	-
	MACRS Depreciation Term (yr)	7	7	7

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stribution Storage at Substation Costfectiveness Result for Base Case

- Benefit/Cost Ratio = 1.19
- Breakeven Capital Cost: \$851/kWh (\$3403/kW) in 2013 inflation adjusted dollars



2015 Distributed Case

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Stribution Base Case: Project Start Year 2015 2020

	Base Case (2015)	Base Case (2020)	
Breakeven Capital Cost in 2013 dollars	\$851/kWh (\$3403/kW)	\$914 /kWh (\$3656/kW)	

Base Case Start at 2020

2015 Distributed Case 1MW, 4hr (battery) 7 Millions CapEx = \$2000/kW, \$500/kWh 11.5% discount rate 83% RT Efficiency Energy & A/S prices escalated 5 3%/yr from CAISO 2011 \$279/kW dist. upgrade cost 4 2% load growth rate 2020 Case Inputs 3 CapEx = \$1750/kW, \$438/kWh 2 Same battery performance as base \$309/kW upgrade cost 1 2% load growth rate 0 Same market inputs as 2020 peaker use case base

Base Case Inputs

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Sonsitivity to Distribution Base Case - Duration 4 r vs. 2hr

	Base Case (4 Hour)	Base Case (2 Hour)
Breakeven Capital Cost in 2013	\$851/kWh	\$1490 /kWh
dollars	(\$3403/kW)	(\$5960/kW)

2015 Distributed Case 2hr



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Sensitivity to Regulation Price 2X multiplier

	Base Case	Base Case (2x Reg)
Breakeven Capital Cost in 2013 dollars	\$851/kWh (\$3403/kW)	\$1307 /kWh (\$5528/kW)

2015 Base Case

Base Case + 2x Reg



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Sensitivity Distribution Load Growth: 2% vs. 4%

				Base Case (2%)		Base Case (4%)	
Breakeven Capital Cost in 2013 dollars)13	\$851/kWh (\$3404/kW)		\$619 /kW (\$2476/k	/h ₩)	
		2015	5 Base (Case	_	Base Case Load Grow	e with High /th Rate 4%
Base Case Inputs	<mark>د</mark> و ل			■ Frequency Regulation	Suc O		
1MVV, 4nr (battery)	Ilio				Villic		
CapEx = \$2000/kVV, \$500/kVVh	₹5			■ Synchronous Reserve (Spin)	25		
11.5% discount rate				Non-synchronous			
83% RT Efficiency	4			Reserve (Non-spin)	4 -		
Energy & A/S prices escalated				System Electric Supply Capacity			
\$279/kW upgrade cost	3 -			Electricity Sales	3 -		
2% load growth rate				Distribution			
2 % load growin rate	0			Investment Deferral	2		
	2			Paid)	2		
				Operating Costs			
	1			■ Financing Costs (Debt)	1 -		
	0			■ Capital Expenditure (Equity)	0		
		Cost	Benefit	(Equity)	-	Cost	Benefit

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Sorage Comparison: Battery (Base) vs. Flow Eattery

			Ba	ise Case	Base Case Flow Batte	e w/ ery – 4h
Breakeven Capital Cost in 2013 dollars		\$8	51/kWh	\$1000 /kW	h	
		(\$:	3403/kW)	(\$4000/kW)		
Base Case Inputs		20 ²	15 Base C	ase	Base Case Flow Bat	e with tery
1MW, 4hr (battery)	<mark>ہ</mark> و			≣Frequency Regulation و ۲	6	
CapEx = \$2000/kW, \$500/kWh	Aillion			Synchronous Reserve		
11.5% discount rate	≥ 5				5	
83% RT Efficiency				™ Non-synchronous Reserve (Non-spin)		
Energy & A/S prices escalated 3%/yr from CAISO 2011	4	-		System Electric Supply Capacity	4	-
\$279/kW upgrade cost				Electricity Sales		
2% load growth rate	3			:	3	_
Flow Battery Inputs				Distribution Investment Deferral		
1MW, 4hr	2			■ Taxes (Refund or Paid)	2	-
17 yr project life				(, , , , , , , , , , , , , , , , , , ,		
CapEx = \$3100/kW, \$775/kWh	1			Operating Costs	1	
No replacements	1			■Financing Costs (Debt)		
	0	Cost	Benefit	Capital Expenditure (Equity)	Cost	Benefit
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erview of Distribution Results: Breakeven pital Costs

2500 2000 Approximate 1500 "Current Costs"* 1000 2015 CPUC Input Costs ۵ 500 (Base Case) All Cases Cost-Effective with CPUC Inputs; Few Cases Cost-Effective at Current C

Breakeven Capital Cost (\$/kWh) in 2013 dollars

* Based on 2011 EPRI Storage Cost Survey and other sources

** "Current costs" applicable to 2-4hr battery, not other technologies contained ELECTRIC POWER RESEARCH INSTITUTE EDGI

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erview of Distribution Case: Benefit-Cost tio with CPUC Inputs



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Conclusions & Next Steps

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erview of all Benefit-to-Cost Ratios **B/C** Ratio



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Overview of findings

- Key findings from modeling analysis
 - Under provided assumptions, no clear conclusions between cost-effectiveness of different storage tech
 - Shorter duration typically allows for higher breakeven costs and improved benefit-to-cost ratios
 - Regulation is valuable for storage and price multiplier (pay-for-performance) drives battery storage profitability significantly
 - System capacity and T&D investment deferral are high value services
 - Higher Energy & A/S price escalation assumptions drive higher values in storage

Reminder: Results provided are valid only under stated CPUC assumptions.

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Conclusions

- In this analysis, ESVT calculated that storage is costeffective under most of the scenarios defined by the CPUC
- Storage still faces significant challenges in terms of integration and deployment in the field
- Cost targets for storage defined in these scenarios have yet to be achieved



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xt Steps – Comments and Reporting

- We would love to hear your comments and feedback to this analysis
- Intend to produce a publicly available EPRI report in the June timeframe to more formally present the results of this analysis
 - Opportunity to incorporate FAQ's from stakeholders and clarifications
- Analysis is still at an early stage! Case runs were completed in a short amount of time. More analysis pending.

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Toank you!

- Active participation from CPUC, CESA, PG&E, SCE, and SDG&E to support our input clarification questions and format inputs in a way that resulted in only a small number of miscommunications
 - Special thanks to Giovanni Damato of CESA for managing the input template
- Great feedback on important tool outputs and formats that will be incorporated into future versions of the ESVT.

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