Energy Storage Update
Status, Trends, Research Directions, and Resources

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Presentation to Maryland PSC Energy Storage WG
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Introduction

EPRI and Energy Storage Research Area

The Electric Power Research Institute

Independent

Objective and scientifically based

Non-profit

Chartered to serve the public benefit

Collaborative

Bring together researchers, industry experts, and policy makers

Together… Shaping the Future of Electricity

Agenda

- Background on the opportunities for energy storage
- Recent trends in cost, value, and deployment of energy storage
- Challenges to storage implementation observed by EPRI
- Focus areas for EPRI's research program
- Energy Storage Integration Council (ESIC) technical collaborative and publications
- Overview of energy storage value and grid services
- Modeling energy storage
  - StorageVET and related research
- Discussion (1 hour reserved)

Q&A after each section and open discussion at end

Energy Storage Background

Uses, Trends, and Research Directions

Historical Challenges for Storage are Fading

Technical Challenges

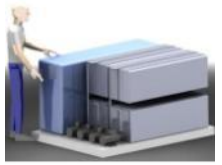
- Performance
- Life and Reliabiltiy
- Integration of communication and control

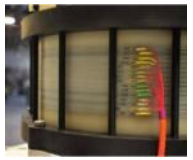
Economic Challenges

- Technology and project costs
- Monetization of benefits

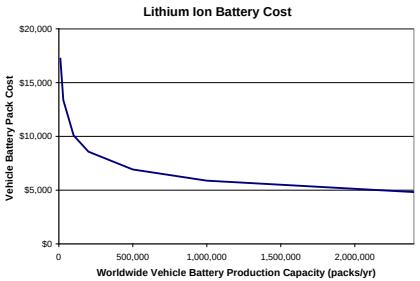
Regulatory Challenges

- Considering unique strength and limitation attributes of storage
- Capturing value and reconciling commitments from multiple services

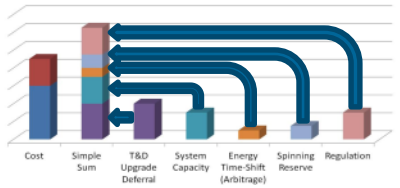




RD&D and Pilots



Downward Cost Trends



New Business Models

Regulatory Rulings

Policy Action

Recent Trends in Storage: Residential

Tesla PowerWall
Announced April 30, 2015

Power: 2 kW
Energy Capacity: 6.4 kWh
Weight: 214 lbs
No Integrated Inverter

Installed Cost: ~$950/kW-hr of storage

2x Energy
2x Power
60% less space
40% relative cost reduction

Tesla PowerWall 2
Announced October 28, 2016

Power: 5 kW
Energy Capacity: 13.5 kWh
Weight: 264 lbs
Fully Integrated Inverter

Installed Cost: ~$580/kW-hr of storage

Recent Trends in Storage: Large-scale Solar + Storage

- September 2015: Kauai Island Utility Cooperative signs a PPA with Solar City/Tesla
  - 17 MW solar array + 52 MWh battery
  - **13.9 cents / kWh** under 20 year PPA
- January 2017: Kauai Island Utility Cooperating signs a PPA with AES
  - 28 MW solar array + 100 MWh battery
  - **11 cents / kWh** under PPA (unspecified period)
- May 2017: Tucson Electric Power signs PPA with NextEra
  - 100MW solar + 30MW / 120MWh battery
  - **4.5 cents / kWh** over 20 year PPA

Source: Solar City

Strong downward trend in cost of dispatchable solar energy, but challenging comparison

Summary: Are we at the Tipping Point?

- Massive investment in lithium ion battery manufacturing has caused the cost of the technology to plummet in 2015-2017 timeframe
- Storage costs have reached an interesting level
  - Significant commercial activity in large “niche” markets such as
    - frequency regulation,
    - peaker replacement,
    - and non-wires alternatives to expensive T&D upgrades
- Integrated system (especially non-battery) costs should continue to fall with commercial experience by integrators and users

EPRI Energy Storage and Distributed Generation Program Mission

Advancing safe, reliable, and environmentally responsible energy storage and distributed generation options

- Tracking technology evolution and providing guidance on power system needs
- Developing advanced tools and methods that accurately account for value and grid impacts
- Supporting implementation and developing of common approaches to integration and use
- Testing and evaluation of product solutions in the lab and in the field





Challenges to Energy Storage Implementation

Energy Storage as a T&D Asset

- Potential to complement and optimize network and feeder investments
  - Solving issues with power quality and reliability constraints
  - Reliability and resiliency
    - Local or neighborhood backup power / microgrids
    - Managing N-x contingency power flows
  - Phase balancing – an alternative to manual operation
  - Life extension / reduced O&M of existing utility assets
  - Losses reduction through voltage / power flow optimization
  - Integration of renewable energy
    - Enhanced value and deliverability

Another tool in the planning and operations toolbox

Technical Issues Impeding the Deployment of Storage on the T&D system

- **Valuation and Technical Analysis**: Understanding and communicating the value of storage and building models for utility planning and operations

- **Project Lifecycle Performance**: Building a track record with real-world performance and reliability data

- **Grid and Process Integration**: Transitioning storage deployment and integration from one-off demonstrations to utility assets

Building a Utility Energy Storage Deployment Program: Pillars to Support Transition from R&D to Operations

PERFORMANCE AND RELIABILITY DATA

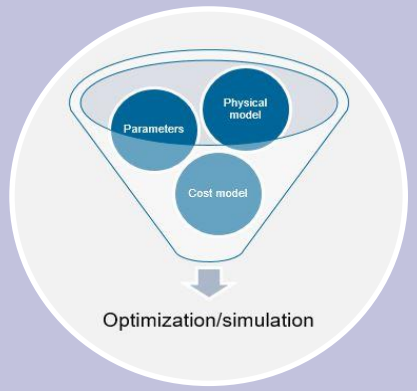
Getting the Data

- Specify relevant data to safety, reliability, value
- Consistent comparison
- Performance/reliability track record

MODELING

Analyzing the Options

- Identify and screen opportunities
- Feasible and optimal location
- Design for optimal lifecycle value



OPERATIONAL EXPERIENCE

Putting into Practice

- Guidelines for deployment
- Customized tools
- Technical training

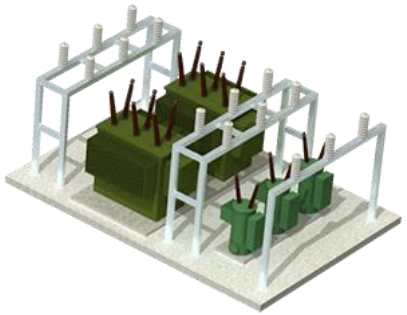
Facilitating Grid-Ready Energy Storage Systems

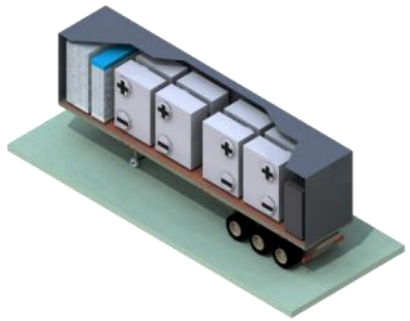
Storage Technology

- Explore technology tradeoffs
- Optimize technology for utility applications

Power Electronics

- Guide common functions and control algorithms
- Ensure efficient and reliable operation





Integrated Product

- Ensure safety and reliability
- Understand cost and performance
- Simplify procurement and operation through standardization of specification and interfaces

Project Deployment

- Establish best practices for siting and permitting
- Standardize grid connection
- Communication and control

Communications and Control

- Developing operational and dispatch algorithms
- Updated communications and grid controllers to accommodate storage functions and services

Energy Storage Integration Council (ESIC)

Open Industry Collaborative to develop common approaches to storage integration challenges

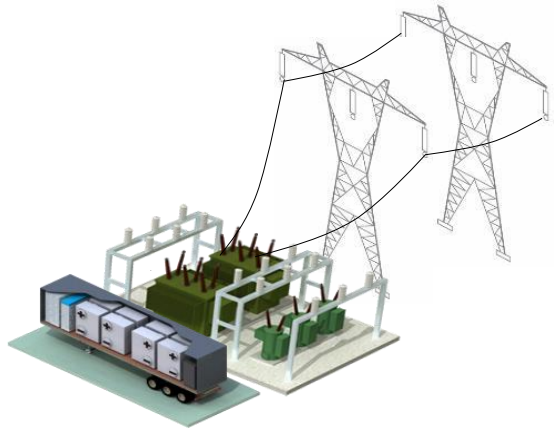
Some Historical Challenges for Early Storage Demos

- Getting to clarity
  - Between utility and regulator
  - Between utility functions
  - Between utility and supply
- Choosing the storage system that meets application requirements and maximizes benefit-cost ratio
- Choosing the best system and measuring cost-effectiveness
- Knowing the applicable codes and standards that apply
- Clarifying Scope of Work and O&M requirements upfront
- Grid integration – Particularly siting, communications/control (IT/OT integration) and interconnection analyses

Energy Storage Integration Council (ESIC) Mission

To advance the integration of energy storage systems through open, technical collaboration

Currently ~1000 participants from utilities, energy storage suppliers, regulators, and the research community



Guided by EPRI's Public Benefit Vision…Practical Needs for Real Deployment

Started in 2013, by sponsorship of funders and advisors of EPRI's Energy Storage Program

More info on products and enrollment at www.epri.com/esic

ESIC Process and Work Products

Goal: Develop publicly-available guidelines and tools through industry collaboration

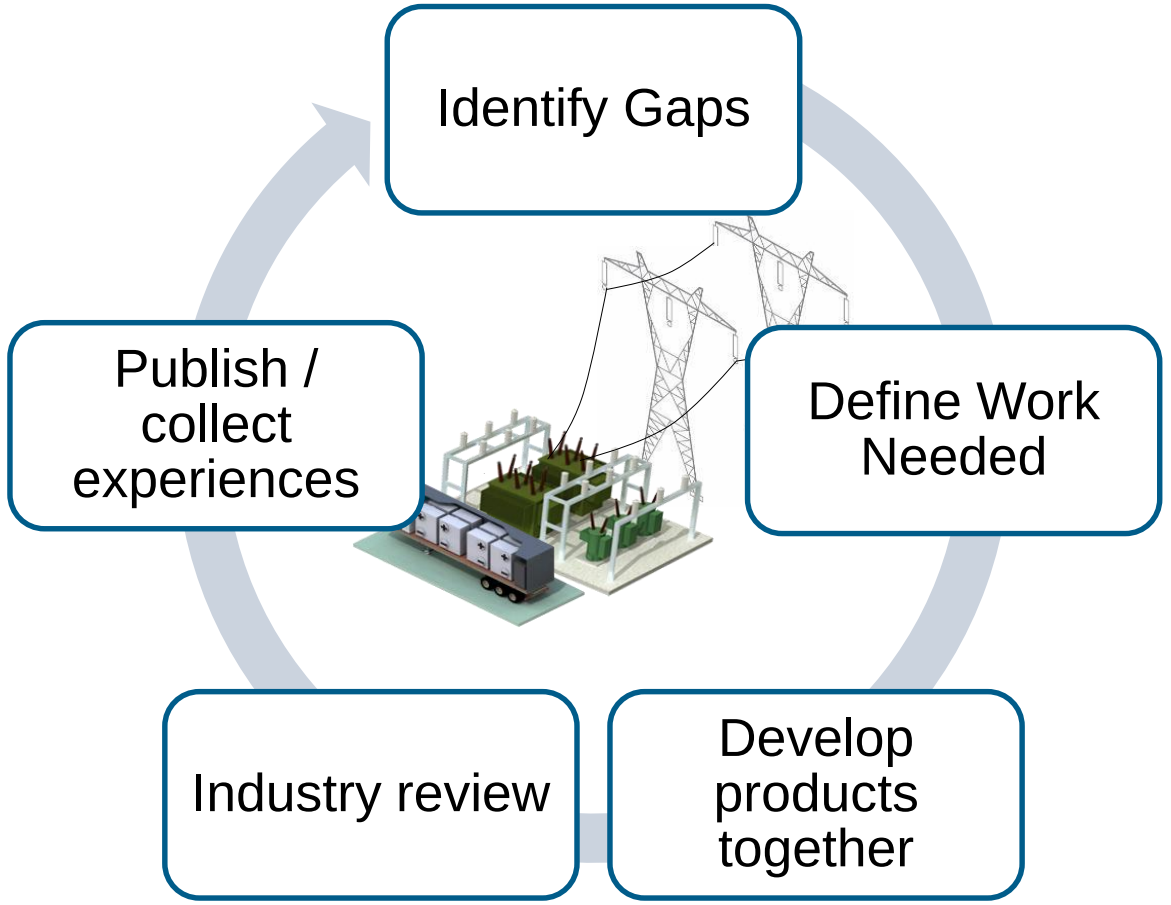
ESIC Published Resources

Energy Storage Cost Template and Tool: 3002006072

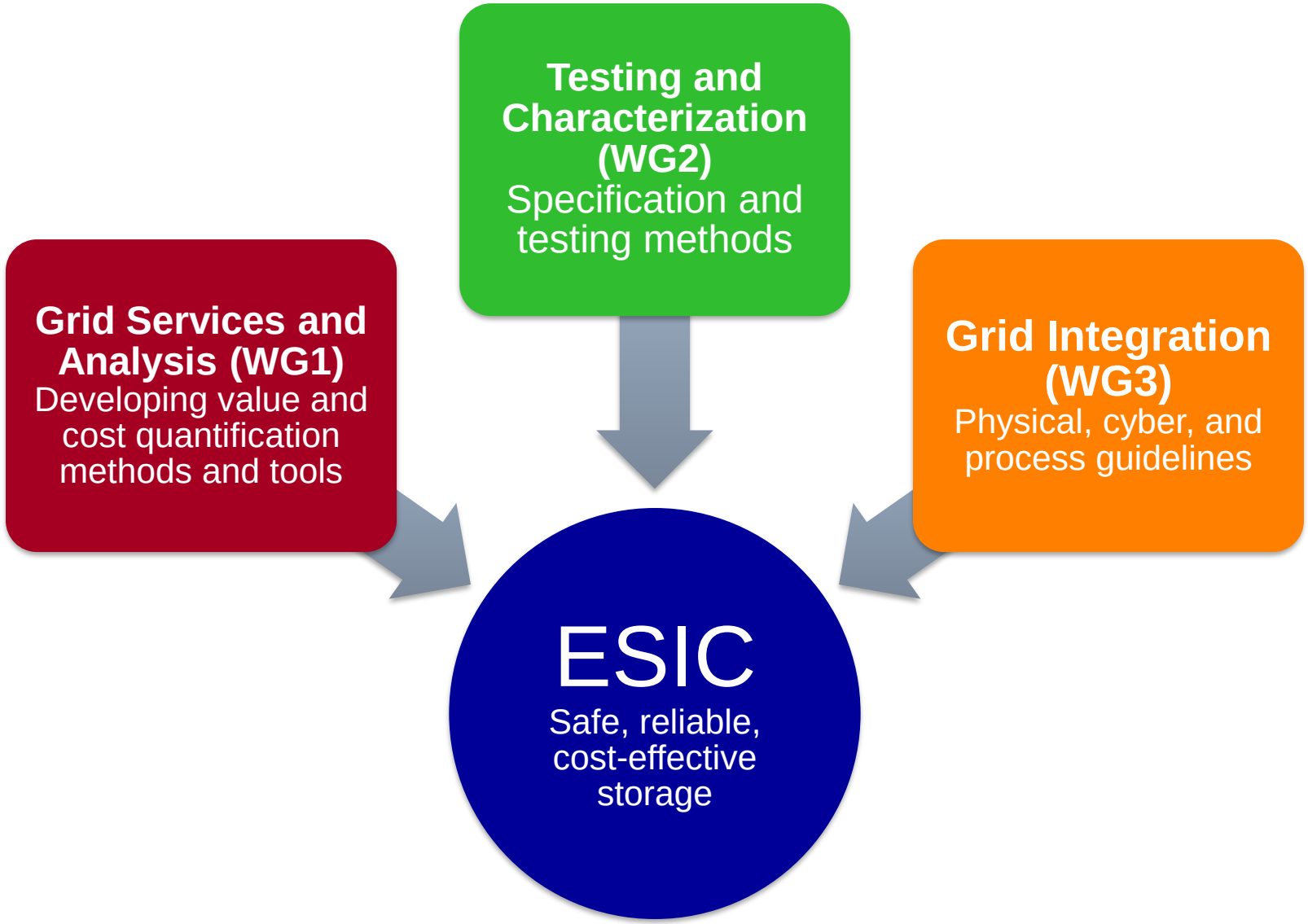
Energy Storage Safety: 2016 3002008308

Integration Guidelines for Energy Storage: 2015 3002006074

Seven (7) published products at ESIC website: www.epri.com/esic



ESIC Major Topic Areas and Working Groups



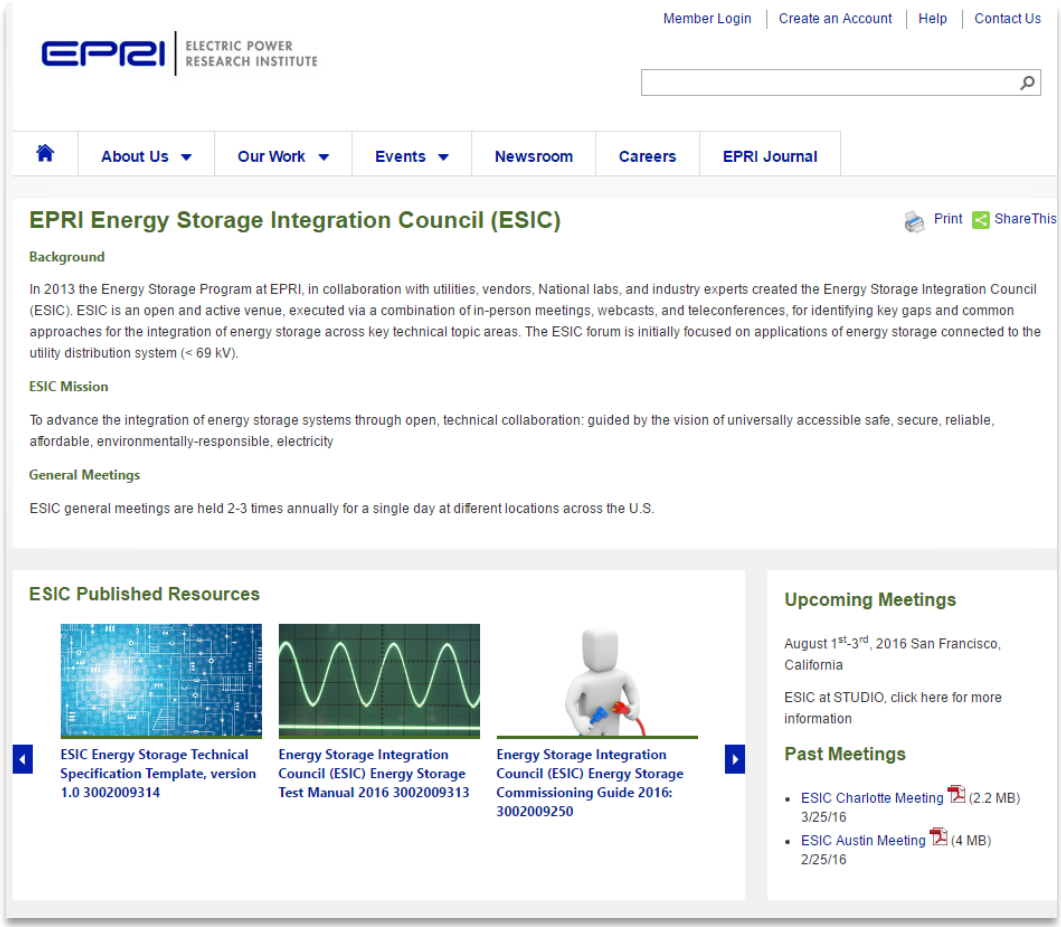
ESIC Meetings Support Different Levels of Engagement

- ESIC general in-person meetings held bi-annually for high level feedback
- Working group updates meet via bi-monthly webcasts for mid-level program
- Subgroups meet via bi-weekly teleconferences to produce and update products

Grid Services and Analysis (WG1)	Testing and Characterization (WG2)	Grid Integration (WG3)
• Cost Tool and Template • StorageVET (Cost-Benefit Analysis Tool) • Modeling Guidelines	• Test Manual • Tech Spec Template	• Implementation Guide • Safety Guide • Commissioning Guide • Common Functions for Smart Inverters

ESIC Products Published to Date

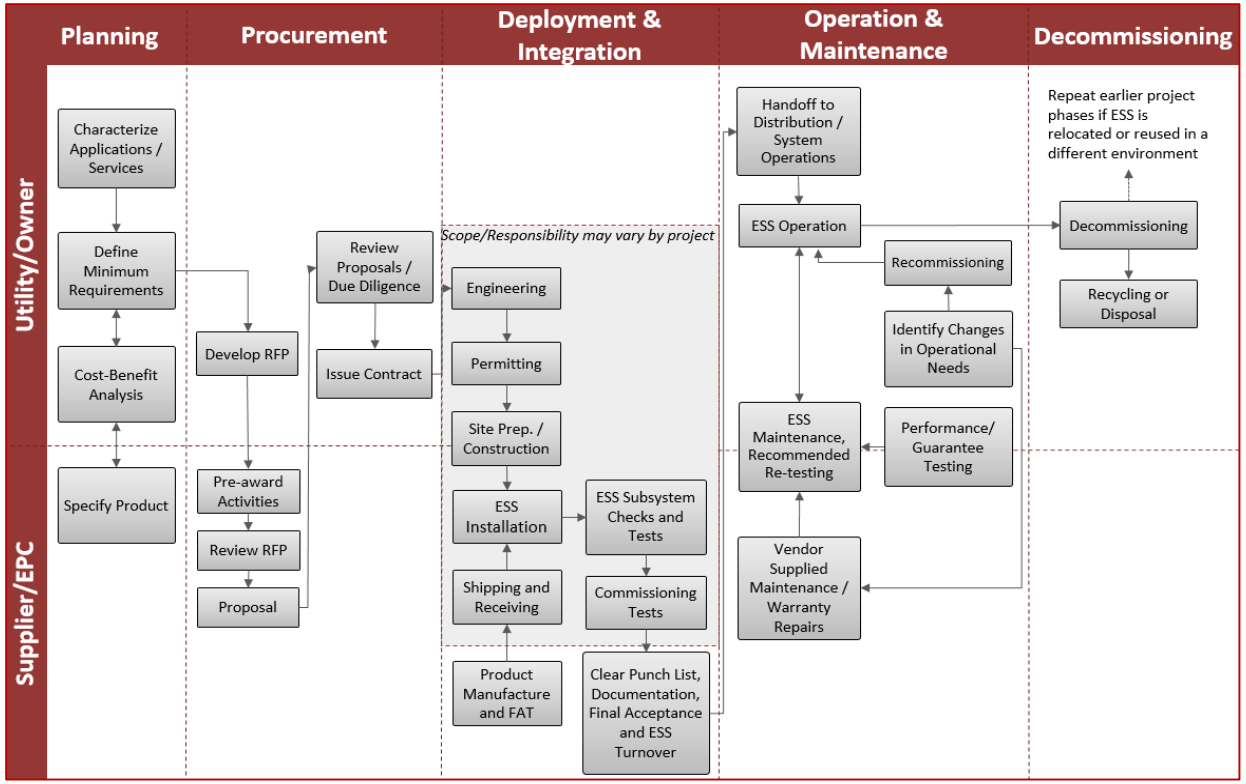
- Energy Storage Implementation Guide
- Energy Storage Cost Tool and Template
- Energy Storage Technical Specification Template
- Energy Storage Safety Guidelines
- Energy Storage Test Manual
- Energy Storage Commissioning Guide
- Common Functions for Smart Inverters V4
- StorageVET and Supporting Documentation (www.storagevet.com)
- Coming Soon: Request for Proposal Guide



Available at ESIC Website: www.epri.com/esic

Energy Storage Implementation Guide

A **practical reference guide** to the **complete lifecycle of an energy storage project** that organizes **ESIC products and publically available materials**, developed for **utility project managers**



Download at www.epri.com/esic

EPRI ELECTRIC POWER RESEARCH INSTITUTE

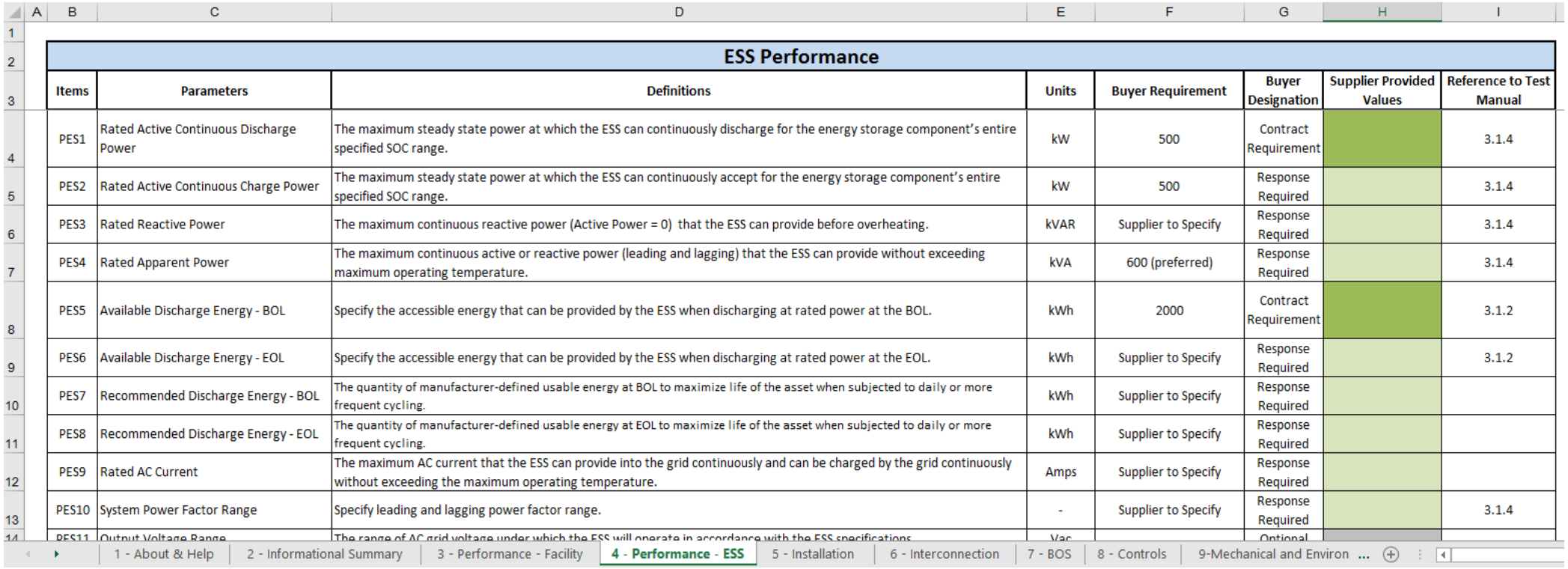
Energy Storage Cost Tool and Template

Excel tool for supporting that **all energy storage project costs** items are accounted for and quotation **requests and responses are clear**

		Vendor Quote			
Cost Line Item	**Cost Input Options**	**Vendor Input**	**Units**	**Vendor Quote**	**Units**
Total ESS Equipment	**Included-Itemized**		**USD**	**$1,525,000**	**USD**
Battery / Energy Storage Medium	Included-Itemized	$1,000,000	USD	$1,000,000	USD
Power Conversion System (PCS)	Included-Itemized	$350,000	USD	$350,000	USD
Control Software	Included-Itemized	$25,000	USD	$25,000	USD
Control Equipment	Included-Itemized	$50,000	USD	$50,000	USD
UPS & Other Electronics	Excluded		USD	Excluded	USD
ESS Thermal Management System	Included-Itemized	$100,000	USD	$100,000	USD
Pre-Engineered ESS Structural Components (e.g. containers & racks)	Excluded		USD	Excluded	USD
Other ESS Purchases	N/A		USD	N/A	USD

Download at www.epri.com/esic

Energy Storage Technical Specification Template



ESS Performance							
Items	Parameters	Definitions	Units	Buyer Requirement	Buyer Designation	Supplier Provided Values	Reference to Test Manual
PES1	Rated Active Continuous Discharge Power	The maximum steady state power at which the ESS can continuously discharge for the energy storage component's entire specified SOC range.	kW	500	Contract Requirement		3.1.4
PES2	Rated Active Continuous Charge Power	The maximum steady state power at which the ESS can continuously accept for the energy storage component's entire specified SOC range.	kW	500	Response Required		3.1.4
PES3	Rated Reactive Power	The maximum continuous reactive power (Active Power = 0) that the ESS can provide before overheating.	kVAR	Supplier to Specify	Response Required		3.1.4
PES4	Rated Apparent Power	The maximum continuous active or reactive power (leading and lagging) that the ESS can provide without exceeding maximum operating temperature.	kVA	600 (preferred)	Response Required		3.1.4
PES5	Available Discharge Energy - BOL	Specify the accessible energy that can be provided by the ESS when discharging at rated power at the BOL.	kWh	2000	Contract Requirement		3.1.2
PES6	Available Discharge Energy - EOL	Specify the accessible energy that can be provided by the ESS when discharging at rated power at the EOL.	kWh	Supplier to Specify	Response Required		3.1.2
PES7	Recommended Discharge Energy - BOL	The quantity of manufacturer-defined usable energy at BOL to maximize life of the asset when subjected to daily or more frequent cycling.	kWh	Supplier to Specify	Response Required		
PES8	Recommended Discharge Energy - EOL	The quantity of manufacturer-defined usable energy at EOL to maximize life of the asset when subjected to daily or more frequent cycling.	kWh	Supplier to Specify	Response Required		
PES9	Rated AC Current	The maximum AC current that the ESS can provide into the grid continuously and can be charged by the grid continuously without exceeding the maximum operating temperature.	Amps	Supplier to Specify	Response Required		
PES10	System Power Factor Range	Specify leading and lagging power factor range.	-	Supplier to Specify	Response Required		3.1.4
PES11	Output Voltage Range	The range of AC grid voltage under which the ESS will operate in accordance with the ESS specifications	Vac		Optional		

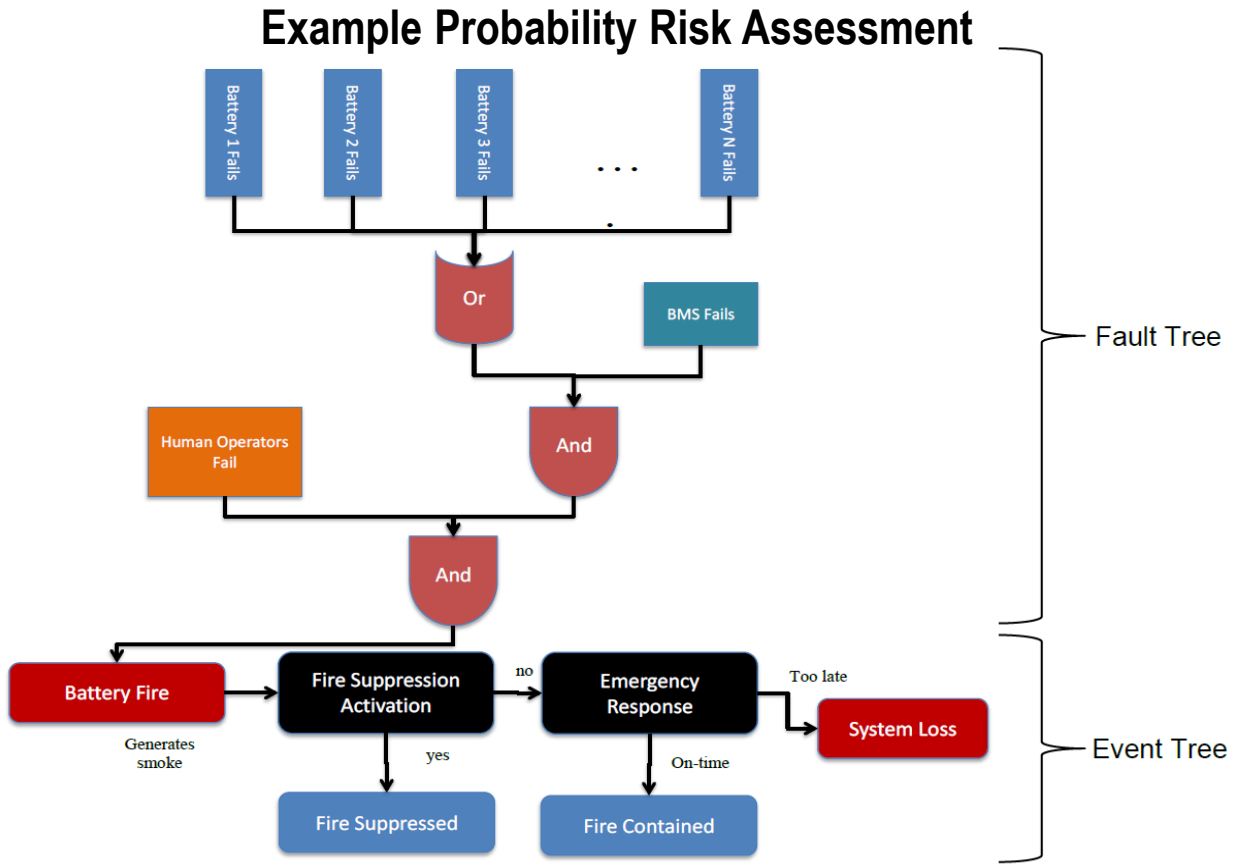
1 - About & Help | 2 - Informational Summary | 3 - Performance - Facility | 4 - Performance - ESS | 5 - Installation | 6 - Interconnection | 7 - BOS | 8 - Controls | 9-Mechanical and Environ ...

Adaptable **Excel tool** for **requesting requirements and receiving specs** for energy storage products and projects.

Download at www.epri.com/esic

Energy Storage Safety Guidelines

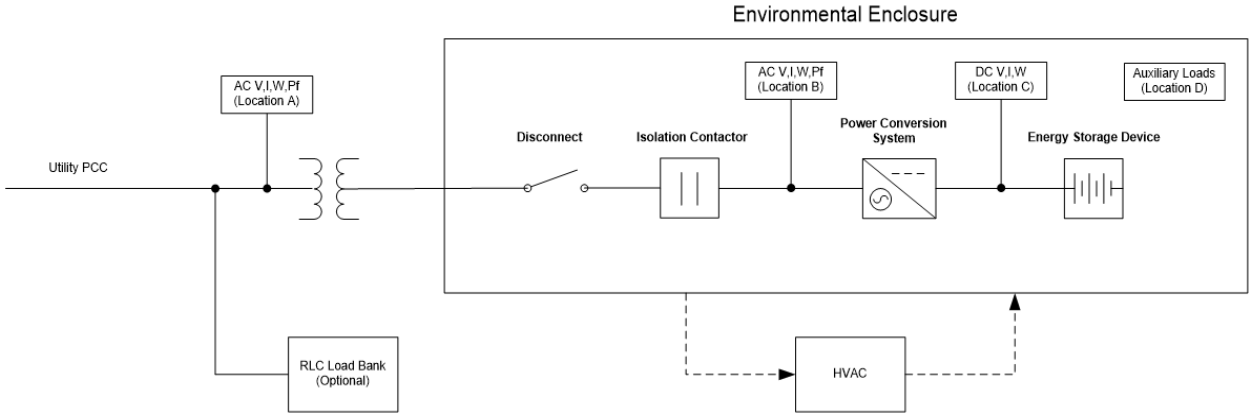
Guidance on energy storage **safety throughout a project**, including **reference codes and standards** organized by functional area.



Download at www.epri.com/esic

Energy Storage Test Manual

Manual to support **consistent characterization** of energy storage performance and functionality, including **specific, detailed procedures**.



- Auxiliary load determination
- Round-trip efficiency
- Available energy capacity
- Charge duration
- Rated continuous power
- Response, rise, settling time
- Harmonic distortion
- Frequency Regulation
- Volt-VAR Regulation

Download at www.epri.com/esic

Attachment B–2: Energy Storage Round Trip Efficiency Test

Test Start Date_____
Test End Date_____
Test Supervisor_____

Test Equipment Type	Test Equipment No.	Test Connection Location	Calibration Date	Installed by	System Checked by

Date/Time	Chamber Temp max/min, °C	Power Factor, min/max	Storage Medium Temp at, start/end, °C	Power Conversion System Temp at, start/end, °C	Ambient Temperature, start/end, °C	Atmospheric pressure, Start/end, mm Hg

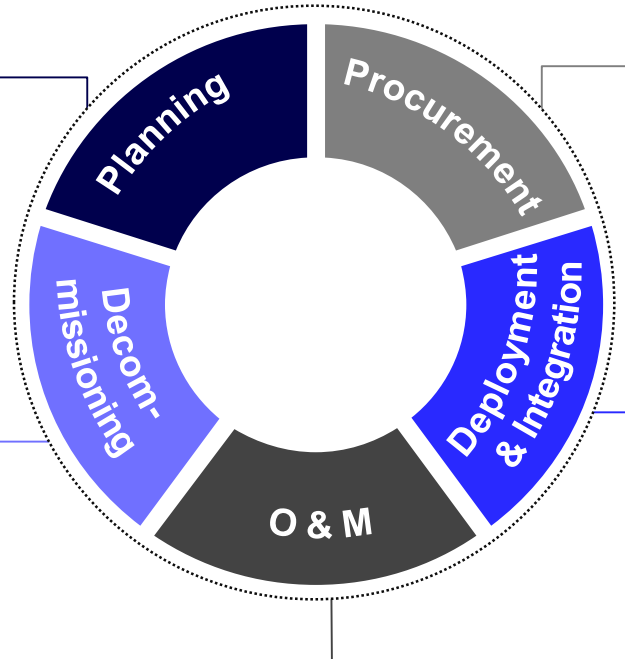
Test Results at Point of Common Coupling

Date/Time	Rated Discharge Power, %	Rated Charge Power, %	PCC Discharge Duration, hours	PCC Charge Duration, hours	PCC Discharge Energy, kWh	PCC Charge Energy, kWh	Aux Load Discharge Energy, kWh	Aux Load Charge Energy, kWh	Roundtrip Efficiency %
	100	100							
	100	100							
	100	100							
	75	75							
	50	50							
	25	25							

Energy Storage Commissioning Guide

Develop a written commissioning plan with requirements, schedule, and budget

Refine commissioning plan and formalize through contract language



Develop a decommissioning plan with risk assessment, safety plan, disposal plan, and shutdown procedures

Commissioning, field and factory acceptance tests ensure system is operating to specification

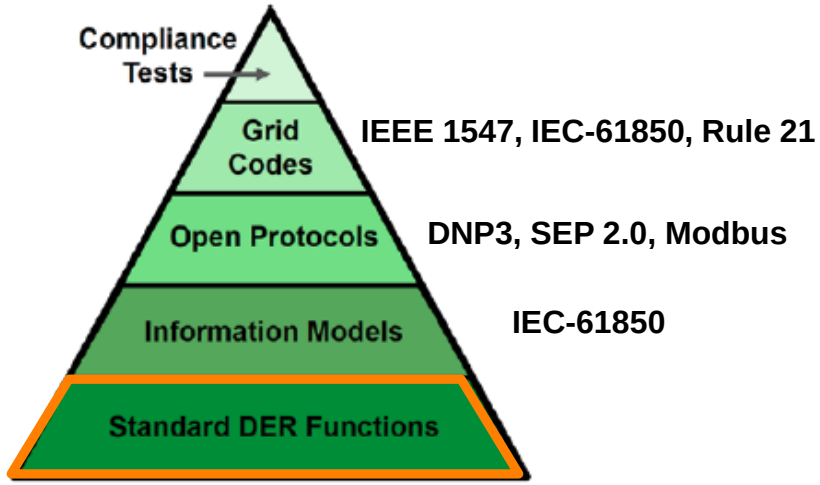
Re-test or recommission as required by maintenance or performance monitoring

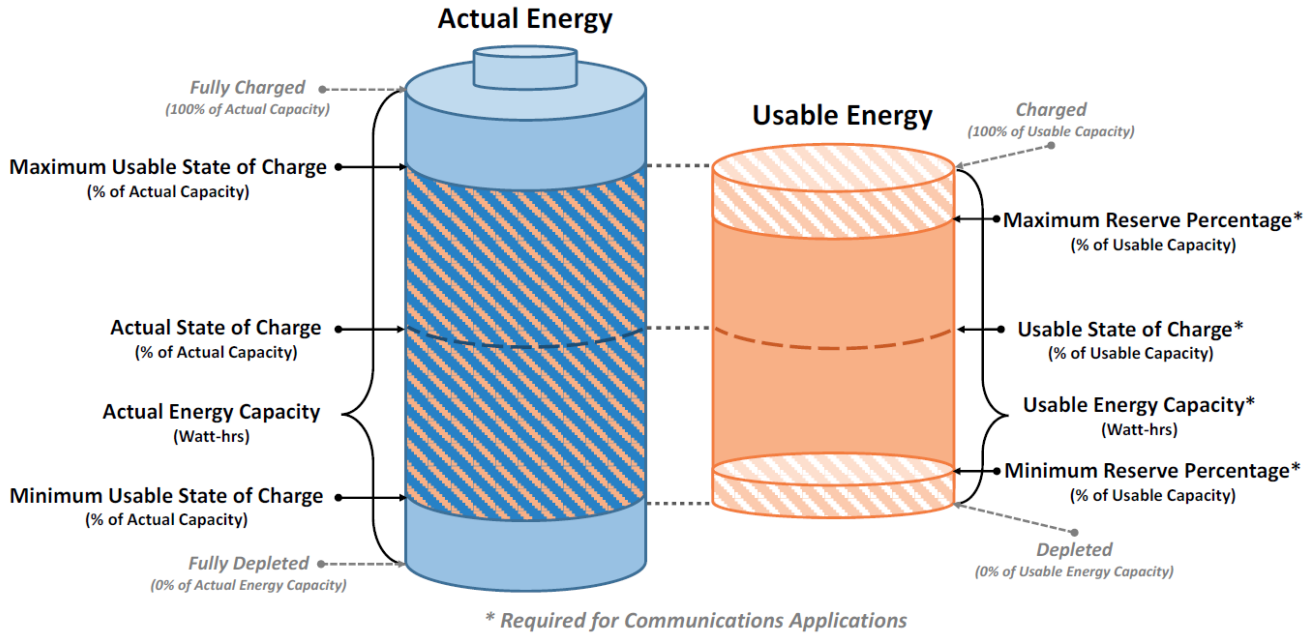
Guidelines for energy storage **commissioning throughout a project**, including **recommissioning and decommissioning**.

Download at www.epri.com/esic

Common Functions for Smart Inverters

Guide to industry on **smart inverter functionality** for PV/Storage function definitions for communication and responses





Download at www.epri.com/esic

Request for Proposal Guide – In Final Draft Review

Guide to support **clear communication of project requirements and scope in an RFP** with links to other ESIC products supporting storage procurement

ENERGY STORAGE PROJECT
DIVISION OF RESPONSIBILITY (DOR)

It	Task Description	Design Criteria (Prelim Desig	Detailed Desig	Purchase Specification	Procure or Supply	Installation	Testing/ Commissioni
	PREPARATION/STRUCTURAL WORK (SITE/BUILDING)						
	Foundation or building (new or modifications)						
	Excavation and grading						
	Site access road						
	Fencing						
	Finishing (gravel)						
	Site Restoration						
	MECHANICAL SYSTEMS WORK						
	Heating, ventilating, and air conditioning						
	Fire protection						
	Safety systems (e.g., spill protection, other)						
	Materials (Anchor bolts, steel structures, other commodities)						
	Painting and coating (if required)						
	ELECTRICAL SYSTEMS/INTERCONNECT WORK						
	Step up Transformers						
	Switches (Disconnect, Recloser)						
	Circuit Breaker						
	Switchgear						
	Bus and instrument transformers						
	Materials (Cable, Conduit, Fittings, Boxes, Other Commodities)						

Responsibility matrix tool

Publication expected October 2017

Get involved with ESIC

- For more information, visit www.epri.com/esic
- Enroll today by sending an email to esic@epri.com with:
  - Name
  - Title
  - Organization
  - Address
  - Email
  - Phone

Understanding the Value of Energy Storage

Grid Services and Value Framing

Energy Storage Can Serve Multiple Purposes

- **Capacity Resource**: Peaker replacement or non-wires alternative
- **Flexibility Resource**: Flexible ramping and ancillary services
- **Reliability / Resiliency Resource:** Electricity inventory for reserves
- **Power Quality Resource:** Volt/Var and Power conditioning system functions

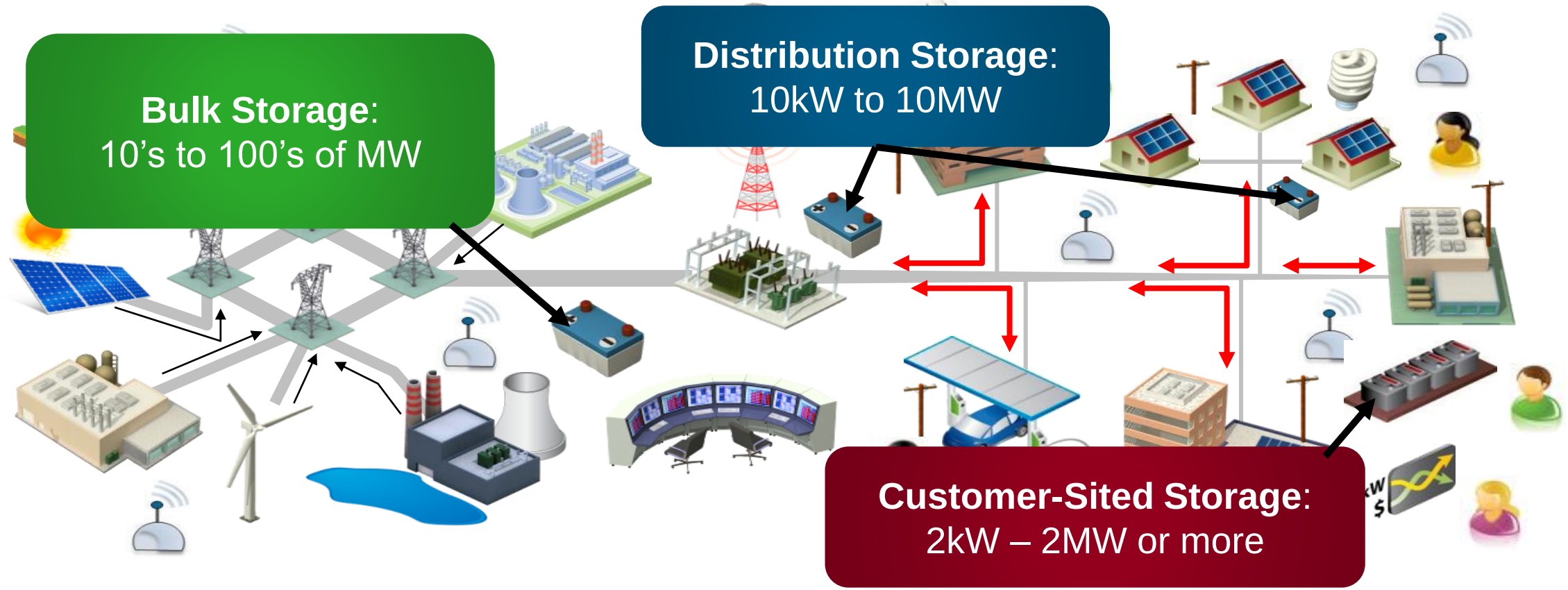





Background on Grid Services

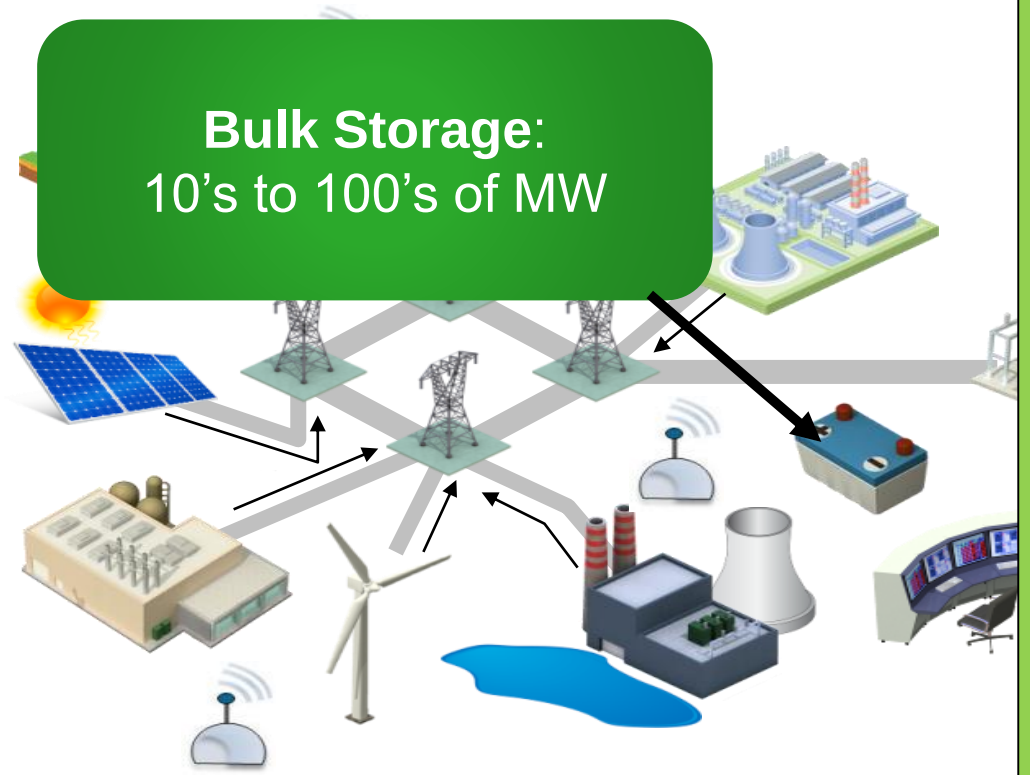
- Grid Services are objectives which resources may address to provide value by meeting objectives with certain requirements
- Services may have long-term or short-term objectives, e.g.
  - Long-term planning – years to months
  - Day-ahead scheduling
  - Hour-ahead operations
  - Real-time operations
- Services may apply to different domains / beneficiaries
  - Bulk / transmission system
  - Distribution system
  - End-customers of electricity

Storage Can be Sited Anywhere on the Power System



Almost limitless permutations of storage and other resources are possible

Transmission-Sited / Bulk Energy Storage



Transmission-Level Grid Services

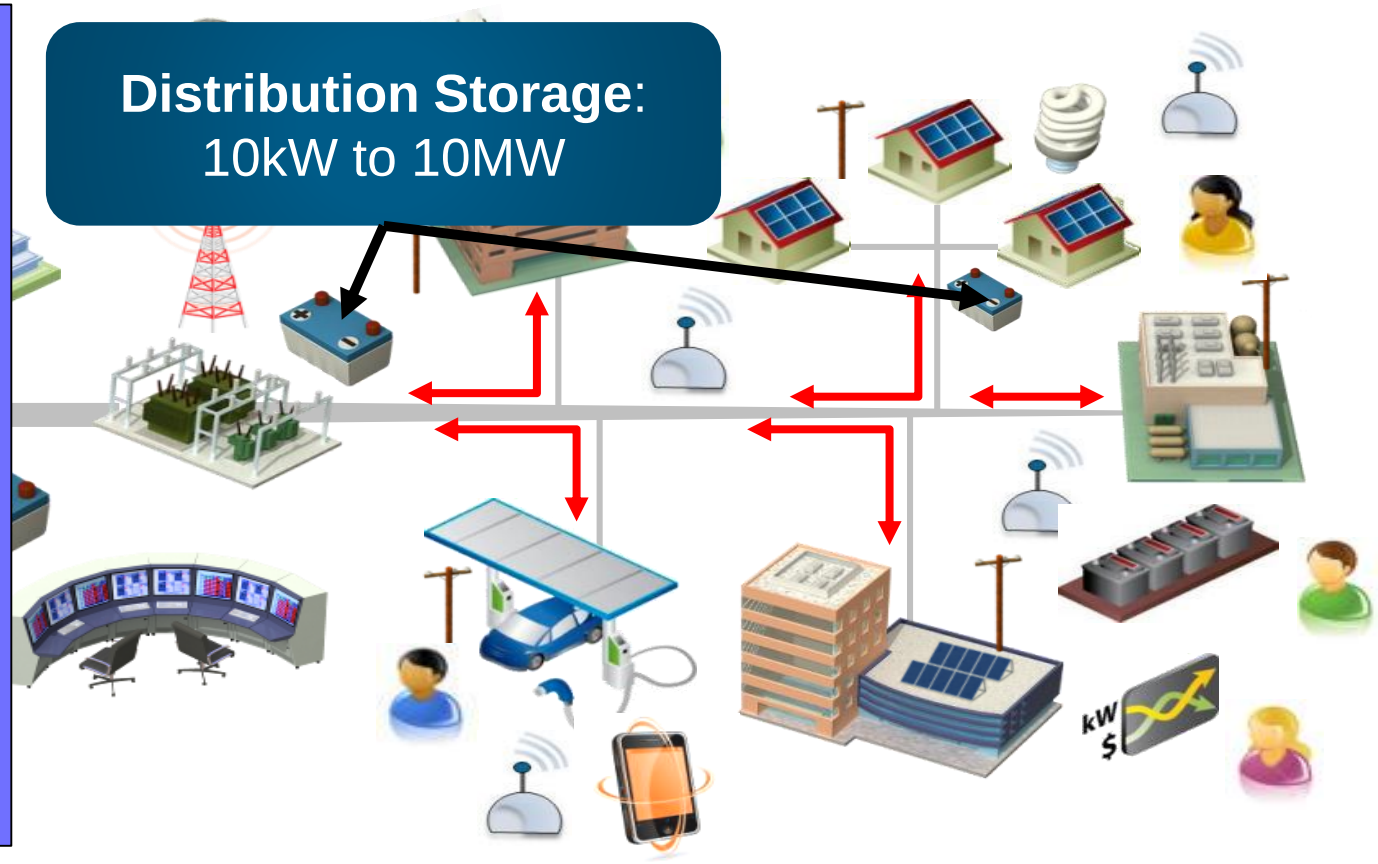
- Long-term planning / resource adequacy
- Transmission upgrade deferral
- Day-ahead/real-time energy shifting
- Frequency regulation
- Frequency response
- Contingency reserve (spin/non-spin)
- Ramping reserve

Bulk storage may serve as alternative for generators or transmission assets

Distribution-Sited Storage

Distribution-Level Grid Services

- Peak shaving / Distribution upgrade deferral
- PQ/ voltage control
- Phase balancing
- Backup/ Microgrid

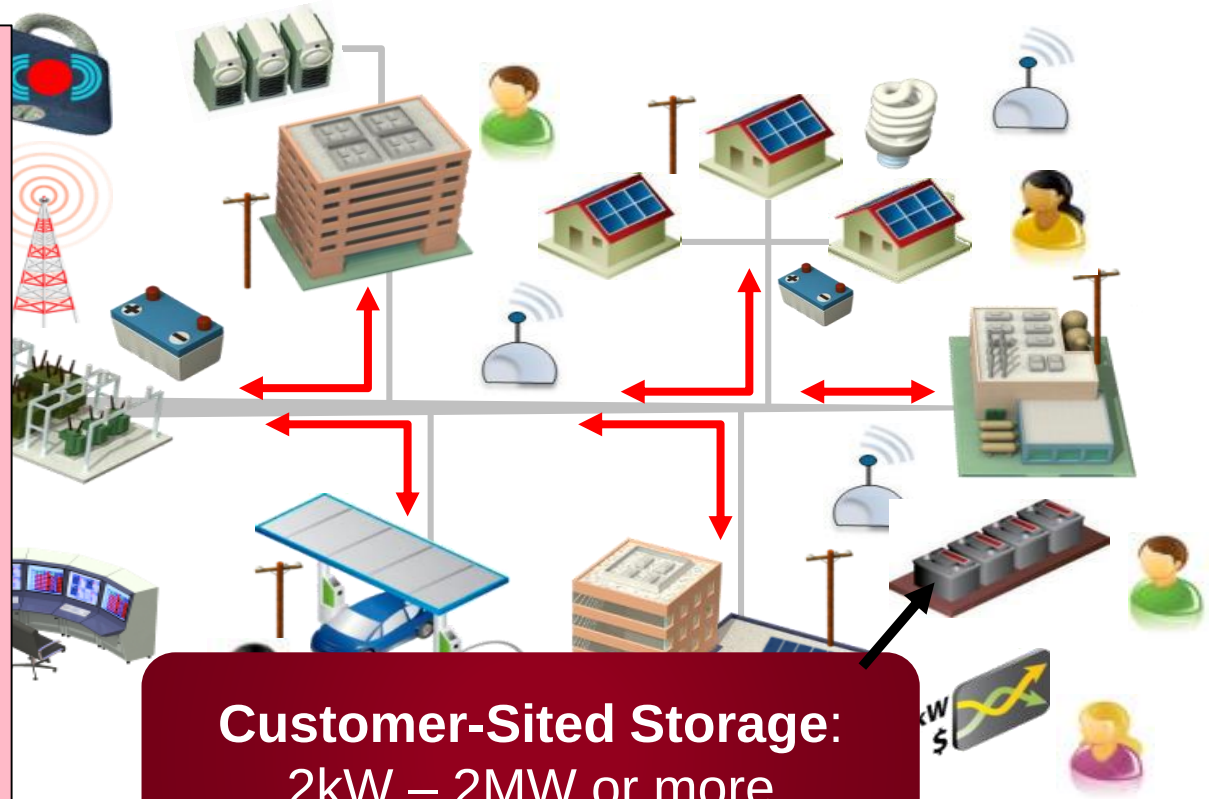


May be able to stack distribution and upstream transmission services

Customer-Sited Storage

Customer-Level Services

- Demand charge reduction
- Time-of-use tariff energy time-shift
- Backup power
- Renewable self-consumption
- Policy incentives – federal ITC, state

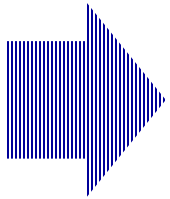


Customer-Sited Storage:
2kW – 2MW or more

May be able to stack distribution and transmission-level services to some degree

Customer Sited Storage - Shift in Cost Test Perspective

Utility/ Ratepayer Perspective



Customer Perspective

How costs **accrue** for delivered electricity

How costs **are collected** for electricity

Stacking customer sited storage benefits and costs requires special care to avoid double-counting

Distributed, Multiple-Use, Stacked Benefit Storage

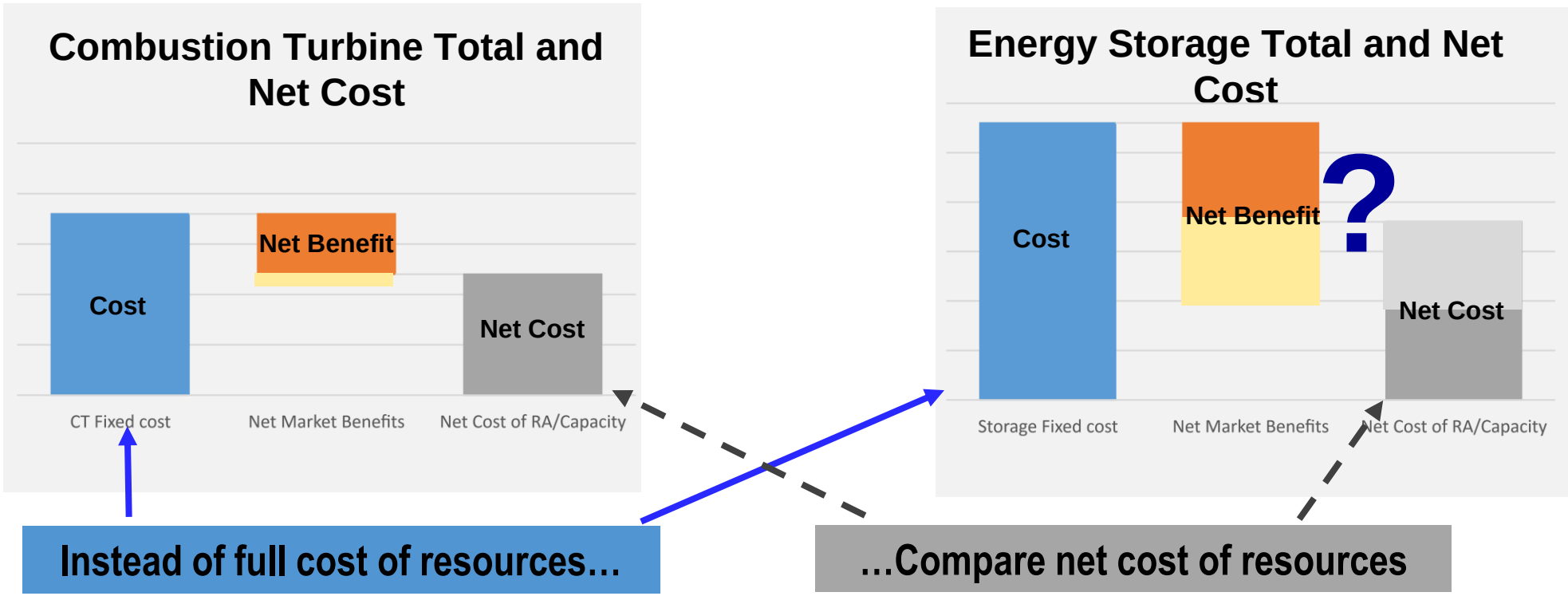
Opportunities

- More services = more benefits
- Support reliability at multiple voltage levels with a single asset
- Fleets may be coordinated and controlled to support T&D network optimization

Challenges

- More services = more objectives, constraints, activity to reconcile
- Which service is chosen if different T&D objectives are in conflict?
- Analytical tools and distributed utility communications & control infrastructure needs further advancement

Net Cost of Reliability – Conventional Asset vs. Storage



For Illustration Only

Operational benefits reduce the net cost of asset for T&D deferral or capacity

Grid Services Summary (May vary slightly by region)

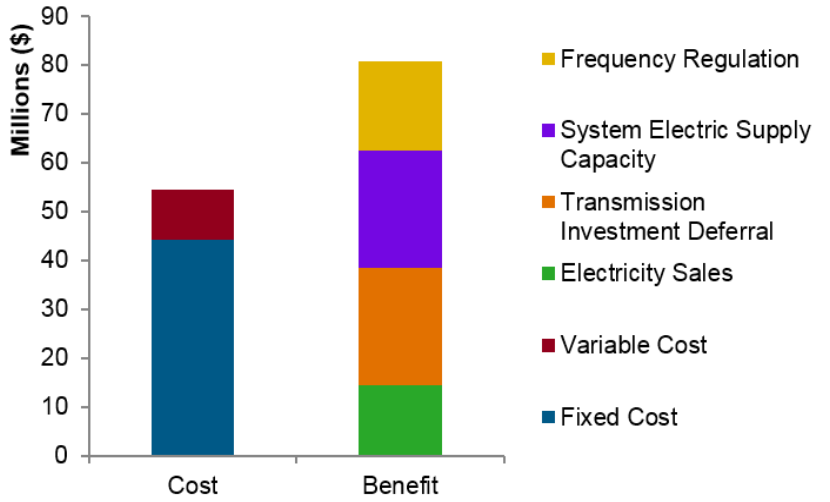
Domain	Service Category	Grid Service
Resource Planning and Operations	Resource Adequacy	Resource Adequacy
	Energy	Day-ahead Energy Time-shift
		Real-time Energy Time-shift
	Ancillary Services	Frequency Regulation
		Spinning Reserve
		Non-Spinning Reserve
		Frequency Response/Inertial Response
		Flexible Ramping
		Black Start
		Voltage/VAR regulation
Transmission	Transmission Planning	Transmission Capacity Investment Deferral
		Transmission Voltage Investment Deferral
	Transmission Operations	Transmission Congestion Relief
		Transmission Voltage/ Reactive Power Support
Distribution	Distribution Planning	Distribution Capacity Investment Deferral (load growth or N-1 Contingency)
		Equipment Life Extension
	Distribution Operations	Distribution Losses Reduction
		Conservation Voltage Reduction (CVR)
		Dynamic Voltage Control
		Backup Power/Microgrid

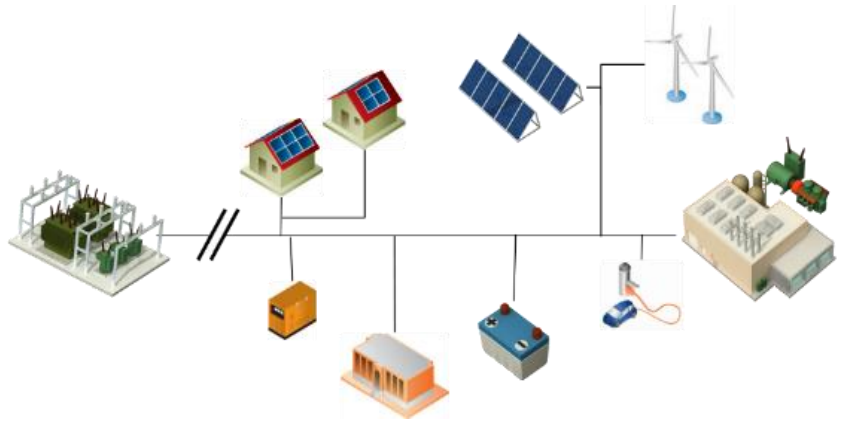
Modeling the Value of Energy Storage

StorageVET and related research

Challenges to Modeling Storage

- Storage and limited energy resources are still not common
- Rules and regulations still are evolving
- Benefit stacking is appealing, but will it be possible
  - More services = more value
  - More services = more requirements → Can they be satisfied?
- Locational value of storage requires site-specific analysis
- Complex optimization between storage degradation and service participation scheduling

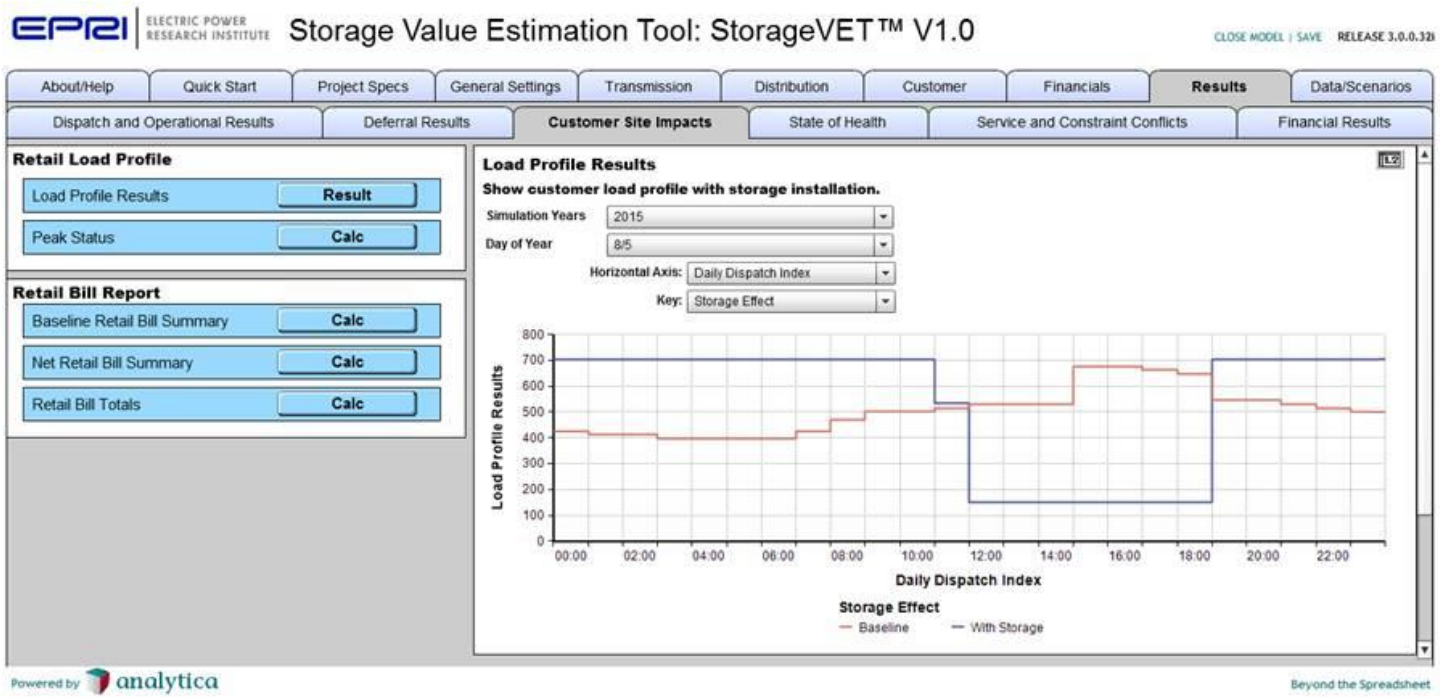


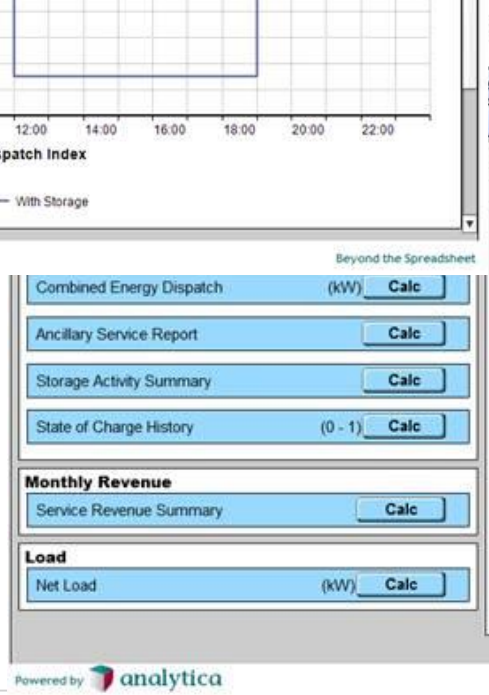


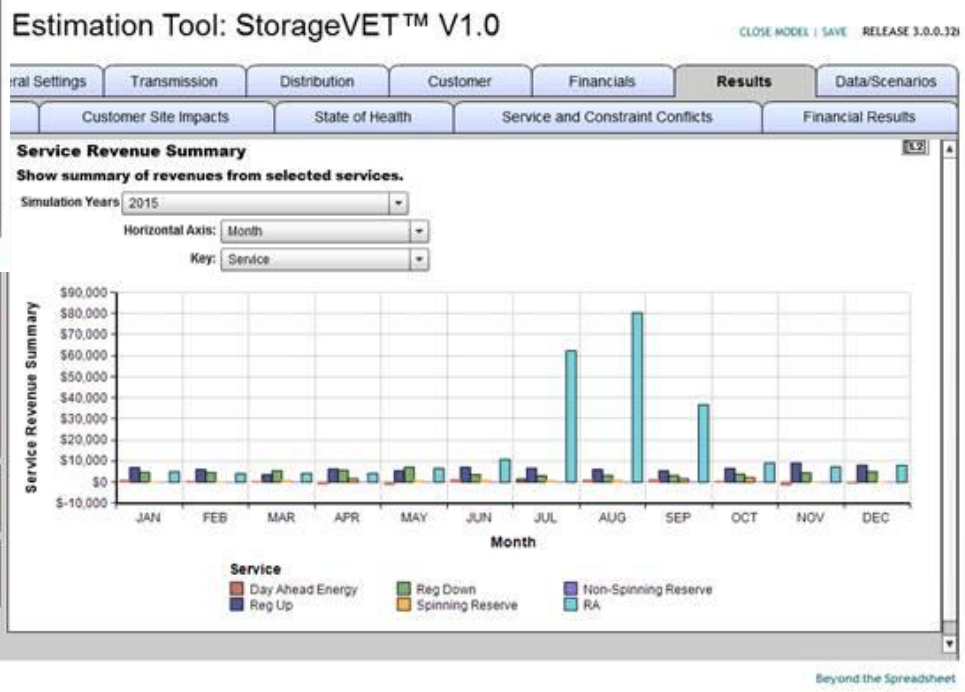
StorageVET™: Public, Web-hosted Valuation Software

- Optimizes and simulates storage project operations and calculates project economics
- Consistently analyzes benefits and costs of storage across range of uses, technologies, locations
- Ongoing validation and enhancement through open forum - Energy Storage Integration Council (ESIC) (www.epri.com/esic)
- More info at www.storagevet.com

StorageVET™ Live: www.storagevet.com







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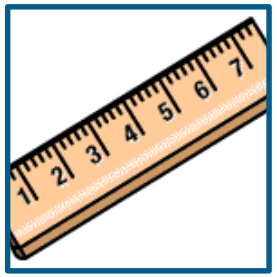
How to Use StorageVET Today

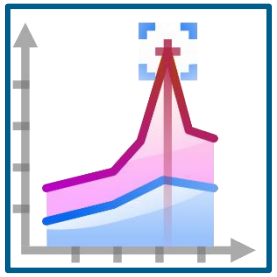
Key Use Cases

Common, Open Platform

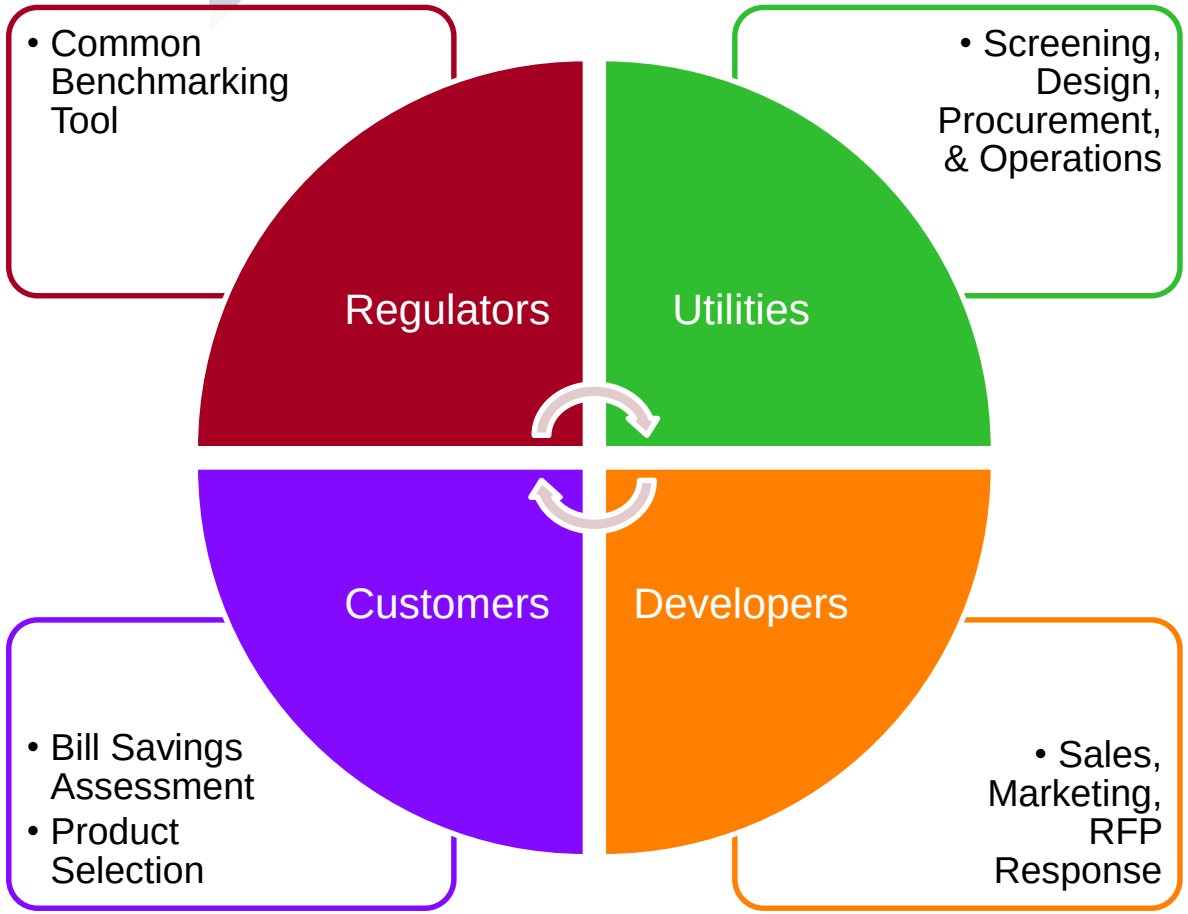
Locating & Screening

Sizing/Designing (stacked services)





Operational Strategies (Customer and Grid)

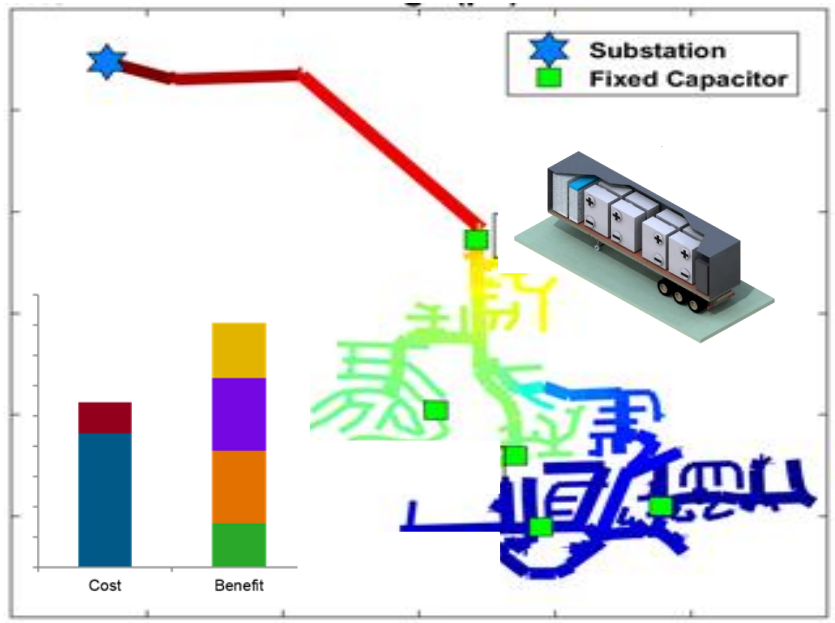


Research Questions Under Investigation

- How does the value of storage differ across jurisdictions?
  - ISO/RTO market rules and drivers
  - Vertically integrated utility without markets
- Where does storage make the most sense?
  - Prioritize high value sites
  - Informed and accelerated decision making
- What are the needs of future planning and operations tools?
  - Bulk planning and system operations
  - Distribution storage integration & locational benefits
  - Improved DER hosting and valuation

Next Steps: StorageVET Validation and Tool Integration

- Model Validation Effort Through ESIC in 2017
- Customize model for different service territories
- Launch StorageVET User Group (2018) to enhance functions
- Integrated Energy Storage Modeling Initiative
  - Analyze and compare storage projects
  - Draw conclusions about utility value
  - Incorporate capacity/voltage constraints




STAKEHOLDER IDENTIFICATION
RFP
SWITCHING AND TAGGING
FEASIBILITY SCREENING
CYBER SECURITY
FORCE MAJEURE
SITING CONSIDERATIONS
MAINTENANCE SCHEDULING
COMMUNICATION AND CONTROL SPECIFICATION
STORAGE IN PRACTICE
MODELING
RELOCATION
COST-BENEFIT ANALYSIS
CSR
EMERGENCY RESPONDERS
TRAINING
RECOMMISSIONING
REFERENCE TESTING
REUSE
DESIGN
TECHNICAL SPECIFICATION
OPERATIONAL CONTROL PROTOCOLS
COMMISSIONING
SAFETY
PREVENTATIVE MEASURES
CONTROL ARCHITECTURE

Together…Shaping the Future of Electricity

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A Brief History of Energy Storage

- 1970's:
  - EPRI begins energy storage research
- 1980's/90's:
  - Compressed Air Energy Storage (CAES) plants in Germany/Alabama, Chino 50MW lead-acid battery project in SCE territory
- 2000-2010:
  - Several utilities experiment with sodium sulfur batteries, flow batteries, and distributed energy storage projects (including ARRA demos in 2010)
- 2011:
  - FERC 755 establishes "pay-for-performance" to enhance compensation for fast, accurate resources (like storage) for frequency regulation
- 2012-13:
  - California PUC Storage Proceeding results in 1.325GW procurement target by 2020

A Brief History of Energy Storage (continued)

- 2014:
  - Southern California Edison selects 261MW storage in all-source RFO for local capacity requirement in anticipation of generator retirements
- 2015-16:
  - Large drops in cost of Li-ion reported with manufacturing capacity scale-up
  - Aliso Canyon procurement: Over 70 MW procured and deployed in SCE/SDG&E territory in ~6 months
  - New York Brooklyn-Queens Non-wires alternative project to defer $1B+ substation upgrade selects significant storage
  - Kauai Utility (KIUC) procures 2 large solar+storage projects
- 2017:
  - Tucson Electric and Connexus (MN) announce large solar+storage projects
  - Massachusetts DOER sets 200MWh energy storage target
  - Maryland energy storage investment tax credit
  - Numerous utility demonstrations and smaller deployment programs

Energy Storage Installed Cost Summary: 2017

Application	Technology	Rating (MW)	Duration (hours)	2017 Cost ($/KW)
Bulk Storage	Pumped Hydro	300-1000	10	1700 - 5100
	CAES	100-300	10	1300 - 2800
	CAES	30-50	6	2000 - 3300
	Lithium Ion	30-50	6	2500 - 3900
	Lead Acid	30-50	6	2800 - 4200
	NaS	30-50	6	2700 - 4200
	Lithium Ion	50-100	4	1600 - 2700
T&D Grid Support	CAES (Above Ground)	10-20	4	2300 - 3500
	Lithium Ion	10-20	4	1800 - 2800
	Lead Acid	10-20	4	2200 - 3700
	NaS	10-20	6	2800 - 4400
	Lithium Ion	1-5	2	1200 - 2000
Frequency Regulation	Lithium Ion	20	0.5	550 - 1200
	Flywheel	20	0.25	800 - 2000

From Energy Storage Cost Summary for Utility Planning. EPRI 3002008877