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 Reliability
• 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

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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

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

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

Seven (7) published products at ESIC website: [www.epri.com/esic](http://www.epri.com/esic)
ESIC Major Topic Areas and Working Groups

Testing and Characterization (WG2)
Specification and testing methods

Grid Services and Analysis (WG1)
Developing value and cost quantification methods and tools

Grid Integration (WG3)
Physical, cyber, and process guidelines

ESIC
Safe, reliable, cost-effective storage
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)
- Cost Tool and Template
- StorageVET (Cost-Benefit Analysis Tool)
- Modeling Guidelines

Testing and Characterization (WG2)
- Test Manual
- Tech Spec Template

Grid Integration (WG3)
- 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
## 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

<table>
<thead>
<tr>
<th>Cost Line Item</th>
<th>Cost Input Options</th>
<th>Vendor Input</th>
<th>Units</th>
<th>Vendor Quote</th>
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<td>USD</td>
<td>N/A</td>
<td>USD</td>
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</tr>
</tbody>
</table>

Download at [www.epri.com/esic](http://www.epri.com/esic)
## Energy Storage Technical Specification Template

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

Download at [www.epri.com/esic](http://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.

Example Probability Risk Assessment

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](http://www.epri.com/esic)
Energy Storage Commissioning Guide

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

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

Refine commissioning plan and formalize through contract language

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](http://www.epri.com/esic)
Guide to support **clear communication of project requirements and scope in an RFP** with links to other ESIC products supporting storage procurement

**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

Bulk Storage: 10’s to 100’s of MW

Distribution Storage: 10kW to 10MW

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

Almost limitless permutations of storage and other resources are possible
Transmission-Sited / Bulk Energy Storage

Bulk Storage: 10’s to 100’s of MW

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

Distribution Storage:
10kW to 10MW

May be able to stack distribution and upstream transmission services
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

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
Operational benefits reduce the net cost of asset for T&D deferral or capacity.
## Grid Services Summary (May vary slightly by region)

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

Key Use Cases

Locating & Screening

Sizing/Designing (stacked services)

Operational Strategies (Customer and Grid)

Common, Open Platform

• Common Benchmarking Tool

• Screening, Design, Procurement, & Operations

• Bill Savings Assessment
• Product Selection

• Sales, Marketing, RFP Response
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
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

<table>
<thead>
<tr>
<th>Application</th>
<th>Technology</th>
<th>Rating (MW)</th>
<th>Duration (hours)</th>
<th>2017 Cost ($/KW)</th>
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<tr>
<td><strong>Bulk Storage</strong></td>
<td>Pumped Hydro</td>
<td>300-1000</td>
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<td>1700 - 5100</td>
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<td>CAES</td>
<td>100-300</td>
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<td>2000 - 3300</td>
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<td>2500 - 3900</td>
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<td>Lead Acid</td>
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<td>2800 - 4200</td>
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<td>NaS</td>
<td>30-50</td>
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<td>2700 - 4200</td>
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<td>1600 - 2700</td>
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<td><strong>T&amp;D Grid Support</strong></td>
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<td>10-20</td>
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<td>1800 - 2800</td>
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<td>Lead Acid</td>
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<td>2200 - 3700</td>
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From Energy Storage Cost Summary for Utility Planning. EPRI 3002008877