Electricity Energy Storage Technology Options: System Cost Benchmarking

IPHE Workshop “Hydrogen- A competitive Energy Storage Medium for large scale integration of renewable electricity”

Casa Palacio de Guardiola, Seville, Spain
15-16 November 2012

Dan Rastler
Electric Power Research Institute
Presentation Outline

• Introduction to EPRI
• Current Energy Storage Landscape
• Benchmarking Costs of Storage Systems
  – Approach
  – Key Findings
• Summary
• Appendix
  – Hydrogen as a Storage Option
  – EPRI New Initiative
  – EPRI Resources
EPRI Energy Storage Program Mission

- Facilitate the development and implementation of storage options for the grid.
- Understanding storage technologies
- Identifying the values of storage
- Defining what storage products must do
- Understanding what must happen for storage to be implemented
The Current Landscape for Energy Storage

Worldwide installed storage capacity for electrical energy

- Compressed Air Energy Storage
  - 440 MWs
- Sodium-Sulphur Battery
  - 304 MWs
- Lithium Ion Battery
  - > 100 MWs
- Adv. Lead-Acid Battery
  - ~70 MWs
- Nickel-Cadmium Battery
  - 27 MWs
- Fly Wheels
  - < 25 MWs
- Redox-Flow Battery
  - < 10 MWs

Over 99% of total storage capacity

Source: Fraunhofer Institute, EPRI - 2012
Overview of Energy Storage Options
Bulk to Distributed Storage Solutions in the Smart Grid

MWs to kWs: Minutes to Hours of Energy Duration
System Cost Benchmarking

Approach and Scope:

- Applications Defined
- Detailed Data Sheets Prepared
- Suppliers Solicited; Battery OEMs, System integrators; Power Conversion System vendors
- Focus on near-term technology options with a look at several emerging systems still in R&D stage; did not look at H2 storage as an option.

Cost Benchmarking Metrics Defined & Methods to Calculate:

- Total Installed Capital Cost ( $ / kW )
- Present Value of Installed cost ( PV $ / kW )
- Levelized cost of Electricity ( $ / MWH )
- Levelized Cost of Capacity ( $ / kW-Yr )
Key Applications Defined along the electric delivery value chain … not comprehensive

<table>
<thead>
<tr>
<th>Key Applications</th>
<th>ISO System Level</th>
<th>Utility Grid Support</th>
<th>Customer Energy Mgt</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bulk Energy Services</td>
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<td>Renewable Integration</td>
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<td>Commercial &amp; Industrial Energy Mgt.</td>
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<td>Home Energy Mgt</td>
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### Detailed Data Sheets Prepared for Vendor Input

#### AECOM ENGINEERING
Revision Date - 11/02/2011

<table>
<thead>
<tr>
<th>LINE NUMBER</th>
<th>APPLICATION</th>
<th>TECHNOLOGY TYPE</th>
<th>SYSTEM SIZE &amp; STATUS</th>
<th>STORAGE CAPACITY (HOURS)</th>
<th>SUPPLIER</th>
<th>TECHNOLOGY CHEMISTRY</th>
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<tbody>
<tr>
<td>1</td>
<td>DESIGN BASIS - General</td>
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<td>2</td>
<td>System Capacity - Net kW</td>
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<td>Hours of Energy storage at rated Capacity - hrs</td>
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<td>Depth of Discharge (DOD) per cycle - %</td>
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<td>5</td>
<td>Energy Capacity - kWh @ rated DOD</td>
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<td>Energy Capacity - kWh @ 100% DOD</td>
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<td>Auxiliaries - kW</td>
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<td>Unit Size - Net kW</td>
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<td>System Foot Print - SF</td>
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<td>System Weight - lbs</td>
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<td>13</td>
<td>Round Trip AC / AC Efficiency - %</td>
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<td>14</td>
<td>Number of cycles / year</td>
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<td>DESIGN BASIS - Temperature</td>
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<td>Year $ for Input Data</td>
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<td>26</td>
<td>Book Life, yrs</td>
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<td>Plant Life, yrs</td>
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<tr>
<td>28</td>
<td>Pre-construction Time, yrs</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

#### SYSTEM COSTS - Equipment & Install

|   | 43 | 44 | 45 | 46 | 47 | 48 | 49 | 50 | 51 | 52 | 53 | 54 | 55 | 56 | 57 | 58 | 59 | 60 | 61 | 62 | 63 | 64 | 65 | 66 | 67 | 68 | 69 | 70 | 71 | 72 |
|---|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|---|---|---|
|   | SYSTEM | ES System | ES Equipment | ES Installation | Enclosures | Owner Interconnection | Equipment | Installation | Enclosures | System Packing | System Shipping to US Port | Utility Interconnection | Equipment | Installation | Site BOP Installation (Civil Only) | Total Cost Equipment | Total Cost Installation | General Contractor Facilities at 15% install | Engineering Fees @ 5% Install | Project Contingency Application @ 0-15% install | Process Contingency Application @ 0-15% of battery | Total Plant Cost (TPC) | Plant Cost - $/kW | Plant Cost - $/kWh @ rated DOD |

#### PLANT CAPITAL COST

<table>
<thead>
<tr>
<th></th>
<th>38</th>
<th>39</th>
<th>40</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PLANT</td>
<td>Power - $/kW</td>
<td>Storage - $/kWh @ rated DOD</td>
</tr>
</tbody>
</table>

#### OPERATING EXPENSES

|   | 73 | 74 | 75 | 76 | 77 | 78 | 79 | 80 | 81 | 82 | 83 | 84 | 85 | 86 | 87 | 88 | 89 | 90 | 91 | 92 | 93 | 94 | 95 | 96 | 97 | 98 | 99 | 100 | 101 | 102 | 103 | 104 | 105 | 106 | 107 |
|---|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
|   | PLANT | FIXED O&M - $/kW-yr | Replacement Battery Costs - $ | Battery replacement - yrs | Variable O&M - $/kWh (Charging or Discharging) | Operating Personnel - number/shift | Operating Shifts/day - @8hrs/shift | Maintenance Personnel - number/shift | Sustainable Minimum Power Input - kW | Nominal Ramp Rate - kW/sec | Discharge Performance: | Maximum Power Output for 15 min - kW | Maximum Power Output for 1 hr - kW | Maximum Power Output for 5 hr - kW | Sustainable Minimum Power Output - kW | Nominal Ramp Rate - kW/sec | Spinning Reserve Response - immediate or time delay | Operating Reserve: | Cold Start-up - kW/Sec | Cold Start-up - kW output in 5 minutes | Duty Cycle: | Cycles/Year | Time to Fully Charge (at Nominal Power Input)-hrs | Time to Functionally Discharge (at Nominal Power Output)-hrs | Minimum Load - % |

Total System Installed Cost Estimated
Acknowledgments and Invited Participants

IONEX Energy Storage Systems, Inc
Isentropic Ltd
LG Chem Power, Inc
NEC
Parker Hannifin
Powergetics
Premium Power
Primus Power
Princeton Power Systems
Prudent Energy
RedFlow
Ricardo Inc.
"RW Beckett Corp"
S&C
Saft
Samsung SDI
Satcon
Siemens
Silent Power
Sunverge
Toshiba International Corp
Xtreme Power
ZBB Energy
Fluidic Energy
ReVolt

A123
ABB Inc
Altairnano
Aquion Energy
Beacon Power
Boston Power
BYD
Chevron Energy Services
Dow Kokam
Dresser-Rand
Dynapower
Ecoult/East Penn
Energy Storage & Power
EnerSys
Enervault
Exide
FIAMM
GE
Green Charge Networks
GreenSmith
EOS
GS Yuasa/GS Battery (USA) Inc.
HighView
International Battery

Note: Not all Vendors Participated in the EPRI Survey
One-line Electrical Diagrams Developed to Estimate Installed Costs

Diagram 2: 250kW; 500kW; 1MW ENERGY STORAGE SYSTEM (ESS) UTILITY AND OWNER INTERCONNECTIONS

Utility Interconnection (UI) Costs

<table>
<thead>
<tr>
<th></th>
<th>250kW</th>
<th>500kW</th>
<th>1MW</th>
</tr>
</thead>
<tbody>
<tr>
<td>1  Remote Switch:</td>
<td>$100,000</td>
<td>$100,000</td>
<td>$100,000</td>
</tr>
<tr>
<td>3  Smart Metering:</td>
<td>$800</td>
<td>$800</td>
<td>$800</td>
</tr>
<tr>
<td>4  Transformer Equipment:</td>
<td>$12,500</td>
<td>$20,000</td>
<td>$30,000</td>
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<tr>
<td>Transformer Installation:</td>
<td>$12,500</td>
<td>$20,000</td>
<td>$30,000</td>
</tr>
<tr>
<td><strong>Subtotal</strong></td>
<td><strong>$125,800</strong></td>
<td><strong>$140,800</strong></td>
<td><strong>$160,800</strong></td>
</tr>
<tr>
<td><strong>$/kW</strong></td>
<td><strong>$503</strong></td>
<td><strong>$282</strong></td>
<td><strong>$161</strong></td>
</tr>
</tbody>
</table>

Owner Interconnection (OI) Costs

<table>
<thead>
<tr>
<th></th>
<th>250kW</th>
<th>500kW</th>
<th>1MW</th>
</tr>
</thead>
<tbody>
<tr>
<td>5  PCS Equipment:</td>
<td>$131,500</td>
<td>$233,500</td>
<td>$367,000</td>
</tr>
<tr>
<td>PCS Installation:</td>
<td>$33,000</td>
<td>$50,500</td>
<td>$92,000</td>
</tr>
<tr>
<td><strong>Subtotal</strong></td>
<td><strong>$164,500</strong></td>
<td><strong>$292,000</strong></td>
<td><strong>$459,000</strong></td>
</tr>
<tr>
<td><strong>$/kW</strong></td>
<td><strong>$650</strong></td>
<td><strong>$504</strong></td>
<td><strong>$459</strong></td>
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</table>

Total (UI and OI) Cost: **$290,300** **$432,800** **$619,800**

**$/kW** **$1,161** **$866** **$620**

System Inverter Scope (kW)

<table>
<thead>
<tr>
<th></th>
<th>22”x8’5”</th>
<th>83”x159”</th>
<th>83”x115”</th>
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</thead>
<tbody>
<tr>
<td>Size (LxWxH):</td>
<td>x8’7”</td>
<td>x31”</td>
<td>x38”</td>
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<tr>
<td>Outdoor Enclosure Y or N:</td>
<td>y</td>
<td>y</td>
<td>y</td>
</tr>
<tr>
<td>Weight:</td>
<td>28000.00</td>
<td>7700.00</td>
<td>4500.00</td>
</tr>
<tr>
<td>Efficiency:</td>
<td>97</td>
<td>97</td>
<td>97</td>
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</tbody>
</table>

NOTES:

* Supplier to provide metering connections at 480V
** Should a new ESS be installed to support an existing Renewable Generation System (RGS) then no additional Utility and Owner Interconnection equipment or cost is required. This assumes that the DC voltage output for the ESS is similar to the RGS.
*** U.G. Distribution System with Pad Mounted Equipment

PCS Power Conditioning System
U.G. UnderGround
Process and Project Contingencies
Assigned Based on Technology Maturity

- Flywheel
- Aqueous Hydride Ion
- Zn / Air
- Zn/ Halogen
- Fe / Cr
- Zn / Br
- Vanadium Redox
- Adv. Pb-Acid
- Li-Ion
- NaNiCl2
- NaS
- CAES
- Pumped Hydro

Included

Percent, %
The 2011-2012 Energy Storage Cost Database

**SUMMARY DATA**
- Application
- Technology

**GRAPHS**
- Total Plant Cost – Application/Technology and System Size
- Power Plant Cost – Application/Technology and System Size
- Storage Plant Cost – Application/Technology and System Size

**LEVELIZED COSTS – 2012**
- Life-cycle Analysis
- Levelized Life cycle cost Analysis Performa

**COST ESTIMATES**

- **CAES**
  - Size: 3MW – 440MW
  - Hrs: 4-8
  - CT-CAES (Above Ground)
  - CT-CAES (Below Ground)
  - BRAYTON-CAES (Below Ground)

- **BULK STORAGE**
  - Size: 20MW – 100MW
  - Hrs: 4-7.2
  - NaS
  - Advanced Lead Acid
  - Zn/Br
  - Vanadium Redox
  - Fe/Cr
  - Zn/Air
  - Zn-Halogen
  - Aqueous Hybrid Ion
  - NaNiCl2

- **RENEWABLE INTEGRATION AND FREQUENCY REGULATION**
  - Size: 1MW – 100MW
  - Hrs: 0.3-1.4
  - NaS
  - Advanced Lead Acid
  - Li-ion
  - Flywheel

- **UTILITY T&D GRID SUPPORT**
  - Size: 1MW – 100MW
  - Hrs: 1-10
  - NaS
  - Advanced Lead Acid
  - Li-ion
  - Zn/Br
  - Vanadium Redox
  - Fe/Cr
  - Zn/Air
  - NaNiCl2

- **DISTRIBUTED ENERGY STORAGE SYSTEMS (DESS)**
  - Size: 25kW-50kW
  - Hrs: 1-5
  - NaS
  - Advanced Lead Acid
  - Li-ion
  - Zn/Br
  - NaNiCl2

- **COMMERCIAL AND INDUSTRIAL (C&I) WITH/WITHOUT PV**
  - Size: 50kW-1.2MW
  - Hrs: 2-10
  - NaS
  - Advanced Lead Acid
  - Li-ion
  - Zn/Br
  - NaNiCl2

- **RESIDENTIAL ENERGY MANAGEMENT (REM) WITH/WITHOUT PV**
  - Size: 2kW-15kW
  - Hrs: 1-8
  - Advanced Lead Acid
  - Li-ion
  - Zn/Br

**APPENDIX**

- Research Approach and Assumptions
- Suppliers
- Power Inverter Systems
- Interconnect Diagrams
- Application Requirements
- Scope
## Metrics used for Cost Comparisons

<table>
<thead>
<tr>
<th>Metric</th>
<th>Generation Example</th>
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</table>
| **Installed Capital Cost - $/ kW**          | 100 MW  
 CT ~ $ 1,150 / kW               |
| Includes all equipment, delivery, installation, interconnection and step-up transformation. Assumed a site was available; however no land costs, permitting or project planning costs were included. | 500 MW  
 CCGT ~ $ 1,100 / kW            |
| **Levelized Cost (of Capacity) - $/kW-Yr.**  | CT ~ $215 /kW-Yr.                  |
| Revenue per kW of discharge capacity needed to cover all lifecycle fixed and variable costs, and provide the target rate of return based on financing assumptions and ownership types. Primarily of interest for comparing to capacity resources, such as a CT. | CCGT ~ $ 498 / kW-Yr.          |
| **Levelized Cost of Energy (LCOE) - ($/MWh)** | CT ~ $ 491 / MWH                |
| Revenue for delivered energy needed to cover all lifecycle fixed and variable costs, and provide the target rate of return based on financing assumptions and ownership types. Primarily of interest for energy resources such as renewable for baseload fossil generation. | CCGT ~ $ 71 / MWH           |
| **Present Value of Life-cycle-Costs - PV $ / kW** | CT ~$2,225/ kW                |
| includes the installed costs, ongoing fixed (including battery replacement) and variable (including charging) operating costs over useful life divided by rated kW. The present value of the annual costs is divided by the kW of energy storage system discharge capacity installed. | CCGT ~ $ 5,152 / kW          |
| **Present Value $/kWh installed**           | NA                                 |
| Same as above divided by *usable* kWh of energy storage capacity |
Cost Benchmarks will vary depending on Ownership Scenario

Note: All Findings in this presentation are for IOU Ownership

Example: 50 MW / 6 hr NaS Battery @ $3071 / kW installed; 365 cycles/yr; 15 year; 75% eff; $30/MWH

CT costs based: aero type: $1100 / kW and 9300 Btu / kWh; other frame type CTs are lower in costs

IOU= investor owned utility, MUNI= municipal utility, IPP= independent power producer
Summary - Total Installed Cost $ / kW

Technology Type for Specific System Sizes Vs Total Plant Cost ($/kW)

Range of Costs Due to: 1. Technology; 2. Hours of Storage; 3. Maturity
Summary-Present Value Installed Cost $ / kW

Notes: All costs in 2012$; Costs will vary significantly based on site-specific conditions;
Financials: IOU ownership; 15 year life; $30/MWH off-peak charging costs; natural gas @ $3/MBtu for CAES
Notes: All costs in 2012$; Costs will vary significantly based on site-specific conditions; Financials: IOU ownership; 15 year life; $30/MWH off-peak charging costs; natural gas @ $3/MBtu for CAES
Summary – Frequency & Renewable Integration

Note: Pumped Hydro Options will also participate in this application
Bulk Storage Systems

System Size - MW

- Zn / Air (1)
- Zinc Bromine (2)
- PH (4)
- CAES (23)
- Fe - Cr (2)
- Aqueous Hybrid...
- NaS (2)
- Vanadium Redox (1)
- NaCl-Ni (3)
- Lead Acid (7)

System Storage - Hr

- 26
- 16

Installed Cost $1000/kW

- 1300

Present Value $1000/kWh

Frequency Regulation

System Size - MW

- PH (4)
- Fe / Cr (1)
- NaCl-Ni (1)
- CAES (27)
- Flywheel (1)
- Zinc Bromine (11)
- Lead Acid (5)
- Li-ion (12)

System Storage - Hr

- 16
- 26

Installed Cost $1000/kWh

- 1300

Present Value $1000/kWh

Site and application specific costs will vary
Benchmarking Current Costs of Storage Options
EPRI 1026601

T&D Grid Support

Site and application specific costs will vary
Challenges – Gap Between Benefits & Costs
(* Reference: EPRI: 1020276 and 1024280)

Technology Type for Specific System Sizes Vs Present Value Installed Cost ($/kWh)

Range of Potential Application Benefits Average to High*

Notes: All costs in 2012$; Costs will vary significantly based on site-specific conditions;
Financials: IOU ownership; 15 year life; $30/MWH off-peak charging costs; natural gas @ $3/MBtu for CAES
Summary and Key Take Aways

• Energy Storage will be a **key option** in addressing renewable integration issues and will be a key asset in the evolving “**Smart Grid**”.

• EPRI Cost Benchmarking and related Value Analysis **essential for business case study**

• Focused on “near-term” solutions -- while we did not look at Hydrogen Storage Options / Solutions in this effort -- **H2 will be evaluated in future work**.

• Cost benchmarking results can only be used to provide a **“directional”** understanding of a system’s costs and capability:

  • **Site and location specific details** as well as application specific use cases will result in varying cost impacts from those detailed in this presentation especially for CAES and Pumped Hydro Options.

  • **Not all suppliers and system integrators are represented** among the technology options - therefore costs within a group may vary.

  • Benchmarking costs – **are not a substitute** for detailed quotes based on detailed specifications and use cases.

  • O&M costs, fixed and variable and component replacement costs **are highly uncertain** at this time. The estimated life-cycle costs will vary with different O&M and periodic replacement cost assumptions.
Appendix – Supplementary Sides

- Hydrogen as a Storage Option
- New EPRI Initiative
- EPRI Resources
Hydrogen as a Storage Option

Key Research Questions:

• What are the key elements of value that hydrogen and/or fuel cells can provide to enabling high penetrations of variable renewables?

• What is the business case for hydrogen and/or fuel cells as an enabler for variable renewables?

• What are the advantages and disadvantages of hydrogen energy storage versus other energy storage technologies?

• What variables have the most influence on the value of hydrogen as an enabler for variable renewables overall? Versus other enabling technologies?

• What is the timeframe for low enough cost hydrogen and/or fuel cell systems to be commercially available that can deliver economic enabling solutions to the issues created by high variable renewables penetrations?

Two Scenarios:

1) Renewable Electricity >> Hydrogen >> Storage >> Energy Conversion >> Electricity

2) Renewable Electricity >> Hydrogen >> Injection into gas pipeline

( other options to consider: methanol; ammonia; other fuels )
Energy Storage – Often Positioned as a Necessary Solution to Intermittent Generation

Challenges:

Technical answers needed to key questions:

- What is the role and technical requirements for energy storage solutions to increase renewable penetration on the grid?

- Can energy storage improve the economics of wind and PV?

- What is the optimal Storage Portfolio including scale and type which provides greatest benefits?

- Role of storage for “grid flexibility” including T&D asset management, Congestion, and Reliability
Energy Storage – Often Positioned as a Necessary Solution to Intermittent Generation

PNNL Study seeks to estimate role of Energy Storage to support Wind Integration

See: National Assessment of Energy Storage for Grid Balancing and Arbitrage: Phase 1, WECC energyenvironment.pnnl.gov/pdf/PNNL-21388_National_Assessment_Storage_Phase_1_final.pdf
New EPRI Initiative
Moving the dial towards commercialization

• Technical Specification for Li-ion Grid Support System Published: EPRI 1025573
• Grid Integration Initiative: EPRI: 1025574

Plans:
• Deploy a 1 MW / 2 MWh Li-ion system on a utility grid based on Spec.
• Bring together data and experiences from other storage installations.
• Apply standard analytic tools to assess impacts and benefits of storage on the grid.
• Collaborative project open to all types of battery technologies.

Synthesize Grid Integration Experiences from many Energy Storage Installations
EPRI Energy Storage -- Key Resources

- Key Reports:
  - **Electric Energy Storage Technology Options: A White Paper Primer on Applications, Costs and Benefits** (EPRI 1020676)
  - Executive summary (EPRI 1022261)
  - **Functional Requirements for Electric Energy Storage Applications on the Power System Grid** (EPRI 1022544)
  - **Energy Storage Cost Benchmarking** (EPRI 1026601)
The Electric Power Research Institute (EPRI)

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  – Generation
  – Power Delivery & Utilization
  – Environment & Renewables

• Major offices in Palo Alto, CA; Charlotte, NC; and Knoxville, TN
EPRI’s Role…

Help Move Technologies to the Commercialization Stage…

Technology Accelerator!
The Current Landscape
Energy Storage Demonstrations in the U.S. - Planned or Under way
List is Not Complete

- SMUD 500 kW / 3 MWh ZnBr
  Sacramento, CA (Premium Power)
  (planned)
- SMUD 5 kW / 9 kWh Li-ion
  (Saft)
- 25 kWh Li-ion
  Berkeley, CA (Seeo)
- Amber Kinetics Flywheel
  Fremont, CA (LLNL)
- PG&E 300 MW Adv. CAES
  Kern County, CA (EPRI)
- SCE 8 MW / 32 MWh Li-ion
  Tehachapi, CA (A123)
- PG&E NaS Battery
  (NGK)
- 25 kWh Li-ion
  Berkeley, CA (Seeo)
- Amber Kinetics Flywheel
  Fremont, CA (LLNL)
- PG&E 300 MW Adv. CAES
  Kern County, CA (EPRI)
- SCE 8 MW / 32 MWh Li-ion
  Tehachapi, CA (A123)
- Vanadium ReDox
  (Prudent Energy)
- 10 MW, First Wind, Kaheawa II, Hawaii
- 15 MW, First Wind, Kahuku, Hawaii
- 11 MW Sempra Generation, Aewahi, Hawaii

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Utilities are Undertaking Numerous Field Trials

Field Trial Deployment Support Cost Basis
Together…Shaping the Future of Electricity

Let us Work Together to Pave the Way for Energy Storage Solutions!

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