DOE/EPRI Electricity Storage Handbook - in Collaboration with NRECA

28 September 2012
Abbas Akhil

Dr. Imre Gyuk and the Department of Energy’s Office of Electricity Delivery & Energy Reliability support is gratefully acknowledged.
Electricity Storage Handbook

**Objective:**
- Compile a “how-to” Handbook that presents the technology capabilities, costs, tools and process for implementing electricity storage projects in the US.

**Approach:**
- Publish an open domain DOE Electricity Storage Handbook in partnership with EPRI
- Collaboration with NRECA – leverage their knowledge base and reaches the large co-operative utility base
- Handbook draws from and updates large body of work of prior work
Handbook Chapters

- Introduction
- Chapter I: Electricity Storage Services to the Electricity Grid
- Chapter II: Electricity Storage Technologies: Performance, Cost and Maturity
- Chapter III: Tools for Evaluating Electricity Storage
- Chapter IV: Storage Systems Procurement and Installation
- Appendices:
  - Trade Associations, Glossary, References (Share Point database), Detail of cost database that is not in the main body
Handbook Introduction

- Identifies/acknowledges support of Sponsors and Advisory Panel
- Excludes thermal storage
- US-centric
- Description of each Handbook Chapter
- Describes an Electricity Storage “SYSTEM”
Chapter I: Electricity Storage
Services to the Electricity Grid

- Updated discussion of DOE and EPRI description of services storage provides to the grid
- “Stacked” Services
- Technical and regulatory do’s and don’ts
- Current regulatory incentives
Chapter II: Electricity Storage Technologies: Performance, Cost and Maturity

- Description of storage technologies
  - Pumped hydro, CAES, Family of Batteries, Flywheels

- Cost database
  - Participating companies and contacts
  - Process used to compile data
  - Charts, tables and schematics
Chapter III: Tools for Evaluating Electricity Storage

- Description of analytical tools for evaluating benefits
  - Screening level, production cost models, electrical stability
  - ES-SELECT, PLEXOS, PROMOD and PSSE, PSLF
  - Data requirements for using tools and expected results

ES-SELECT Sample Screen

Select A Grid Location for deploying ES
Select the Main or First ES Application
Select Additional ES Applications to be bundled together
Select Feasible ES Options From a suggested List
Select Economic and Technical Parameters for Graphic Comparison & Sensitivity Analyses
Chapter IV: Storage Systems Procurement and Installation

- Recommended procurement process
  - Sample RFI and RFP; Specification of sample system
- System test facilities: Sandia and KEMA
- Acknowledges need and current efforts to develop test standards and protocols by DOE and EPRI
- Past storage projects: History and relevance
- International Storage Project database
Handbook Appendices

- **Trade Associations**
  - ESA and CESA: Mission, Activities and websites
  - Major events: ESA Annual Meetings, EESAT event

- **Glossary of Terms**
  - Condensed from ESA’s list (work in progress)

- **References**
  - Share Point collection of reports from DOE, EPRI (public domain); Academia; Industry

- **Details of cost database**
  - Individual datasheets, additional tables and charts to provide additional detail
Cost Database - Participants

A 123
ABB Inc
Altair Nano
Aquion Energy
Boston Power
Beacon Power
Dow Kokam
Dresser-Rand
Dynapower
Energy Storage and Power
East Penn
EnerSys
Enervault
Exide
FIAMM
Fluidic Energy
GE
Green Charge Networks
Greensmith
EOS
GS Yuasa
International Battery
IONEX Energy Storage Systems
Isentropic, Ltd.
LG Chem Power, Inc.
NEC
Parker Hannifin
Powergetics
Premium Power
Primus
Princeton Power Systems
Prudent Energy
RedFlow
ReVolt
RW Beckett Corp.
International Battery
S&C
Saft
Samsung
Satcon
Siemens
Silent Power
Sunverge
Toshiba International Corp
Xtreme Power
ZBB Energy
Cost Database - Process

- Identified 6 high-value, representative storage services
  - Bulk Storage, Frequency Regulation, T&D, DESS/C&I, Residential, and PV
- Polled 40+ vendors for component and system cost, fixed and variable O&M, installation costs
- Summarized results in tabular and chart formats
- Developed schematics for each application suggesting interconnection requirements
Battery Systems

CAES & Pumped Hydro

Technical Maturity: Commercial Stage

<table>
<thead>
<tr>
<th>Technology Type</th>
<th>Supplier</th>
<th>Unit Capacity Gross MW</th>
<th>Storage Hrs</th>
<th>Capacity MWh</th>
<th>AC Eff. %</th>
<th>Cycles /yr</th>
<th>Batt. Repl. yrs</th>
<th>Total Equip. Cost $/kW</th>
<th>Total Equip. Cost $/MWh</th>
<th>Power Comp. $/kW</th>
<th>Storage Comp. $/kW</th>
<th>Fixed O&amp;M $/kW-yr</th>
<th>Variable O&amp;M $/kW</th>
<th>LCOE $/MWh</th>
<th>LCOE $/kW-Yr</th>
<th>PV Inst. Cost $/kW</th>
<th>PV Inst. Cost $/MWh</th>
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<tbody>
<tr>
<td>Brayton CAES (Below Ground)</td>
<td>S9 - 1</td>
<td>103 8.0</td>
<td>824</td>
<td>74%</td>
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<td>$130</td>
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<td>$112</td>
<td>$143</td>
<td>$20</td>
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<tr>
<td>Sodium Metal Halide</td>
<td>S9 - 2</td>
<td>136 8.0</td>
<td>1,088</td>
<td>74%</td>
<td>$1,124</td>
<td>$143</td>
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Technical Maturity: Demonstration Stage

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<th>Unit Capacity Gross MW</th>
<th>Storage Hrs</th>
<th>Capacity MWh</th>
<th>AC Eff. %</th>
<th>Cycles /yr</th>
<th>Batt. Repl. yrs</th>
<th>Total Equip. Cost $/kW</th>
<th>Total Equip. Cost $/MWh</th>
<th>Power Comp. $/kW</th>
<th>Storage Comp. $/kW</th>
<th>Fixed O&amp;M $/kW-yr</th>
<th>Variable O&amp;M $/kW</th>
<th>LCOE $/MWh</th>
<th>LCOE $/kW-Yr</th>
<th>PV Inst. Cost $/kW</th>
<th>PV Inst. Cost $/MWh</th>
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<tbody>
<tr>
<td>CT-CAES (Above Ground)</td>
<td>S12 - 2</td>
<td>50 5.0</td>
<td>250</td>
<td>45%</td>
<td>$1,875</td>
<td>$313</td>
<td>$938</td>
<td>$156</td>
<td>$16</td>
<td>$0.0005</td>
<td>$224</td>
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<tr>
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<td>75%</td>
<td>$5,334</td>
<td>$1,067</td>
<td>$482</td>
<td>$970</td>
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<td>$1,947</td>
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<td>S17 50 5.0</td>
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<td>$2,823</td>
<td>$565</td>
<td>$487</td>
<td>$467</td>
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<td>$312</td>
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<tr>
<td>CT-CAES (Below Ground)</td>
<td>S11 100 4.0</td>
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<td>$4,326</td>
<td>$1,082</td>
<td>$546</td>
<td>$945</td>
<td>$4</td>
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<td>$1,954</td>
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<tr>
<td>CT-CAES (Below Ground)</td>
<td>S36 100 7.2</td>
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<td>75%</td>
<td>$3,168</td>
<td>$440</td>
<td>$490</td>
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Technical Maturity: R&D Stage

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<th>Cycles /yr</th>
<th>Batt. Repl. yrs</th>
<th>Total Equip. Cost $/kW</th>
<th>Total Equip. Cost $/MWh</th>
<th>Power Comp. $/kW</th>
<th>Storage Comp. $/kW</th>
<th>Fixed O&amp;M $/kW-yr</th>
<th>Variable O&amp;M $/kW</th>
<th>LCOE $/MWh</th>
<th>LCOE $/kW-Yr</th>
<th>PV Inst. Cost $/kW</th>
<th>PV Inst. Cost $/MWh</th>
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<td>Aqueous Hybrid Ion</td>
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<td>250</td>
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<td>Zn / Air</td>
<td>S20 50 8.0</td>
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<td>$443</td>
<td>$164</td>
<td>$4</td>
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<td>$164</td>
<td>$359</td>
<td>$534</td>
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Sodium Metal Halide

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<tr>
<td>Sodium Metal Halide</td>
<td>S16 106 5.0</td>
<td>300</td>
<td>88%</td>
<td>$5,334</td>
<td>$1,067</td>
<td>$487</td>
<td>$487</td>
<td>$4</td>
<td>$0.0005</td>
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<tr>
<td>Vanadium Redox</td>
<td>S32 50 5.0</td>
<td>250</td>
<td>75%</td>
<td>$3,168</td>
<td>$434</td>
<td>$792</td>
<td>$1,415</td>
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<tr>
<td>Zinc Bromine</td>
<td>S29 50 5.0</td>
<td>250</td>
<td>86%</td>
<td>$5,334</td>
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<td>$487</td>
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<td>S29 100 5.0</td>
<td>500</td>
<td>60%</td>
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Energy vs Power

$/kW vs Power

$/kWh vs Power
Summary Cost Charts - Detail

Bulk Storage

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

Installed Cost $1000/kW

Present Value $1000/kW

LCOE $1000/MWh
Handbook Details

- First review draft to Sponsors – September 28
- Advisory Panel Review - October 5
- Public release of final version by end of 2012
- Paper copy and pdf version in two volumes
  - Volume 1 – Handbook
  - Volume 2 – Appendices
Authors and Contributors

- PI: Georgianne Huff & Abbas Akhil
- EPRI: Haresh Kamath & Ben Kaun
- NRECA: Dale Bradshaw
- AECOM: Dave Gauntlett

Dr. Imre Gyuk and the Department of Energy’s Office of Electricity Delivery & Energy Reliability support is gratefully acknowledged.