

DOE/EPRI Electricity Storage Handbook - in Collaboration with NRECA

28 September 2012

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



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DOE/EPRI 2012 Electricity Storage Handbook in Collaboration with NRECA


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- **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**
- **Recognizes 2003 edition of Handbook**
- **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

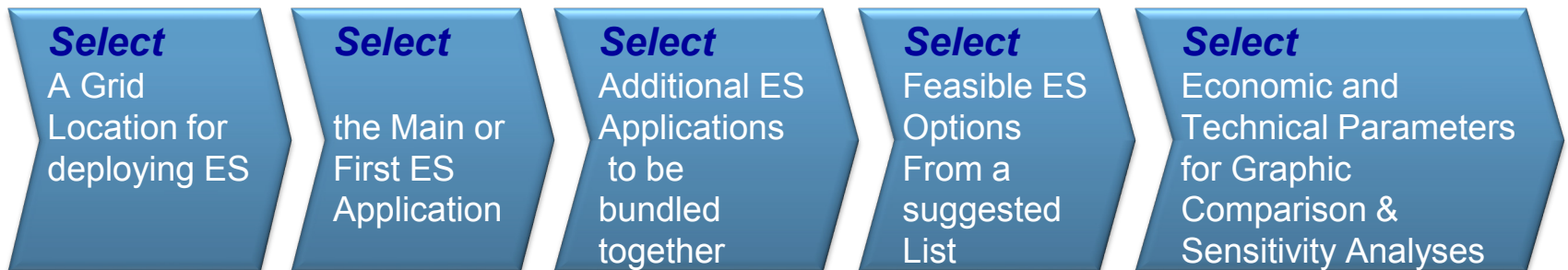
- **Description of storage technologies**
 - Pumped hydro, CAES, Family of Batteries, Flywheels

- **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



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**

CAES & Pumped Hydro

Technology Type	Supplier	Unit Capacity Gross MW	Storage Hrs	Capacity MWh	Energy Rate & AC Eff. %	Total Equip. Cost \$/kW	Total Equip. Cost \$/kWh	Power Comp. \$/kW	Storage Comp. \$/kWh	Fixed O&M \$/kW-yr	Variable O&M \$/kWh	LCOE \$/MWh	LCOE \$/kW-Yr	PV Inst. Cost \$/kW	PV Inst. Cost \$/kW
Technical Maturity: Commercial Stage															
BRAYTON-CAES (Below Ground)	S9 - 1	103	8.0	824	74%	\$1,040	\$130	\$921	\$15	\$5	\$0.0035	\$130	\$379	\$610	\$4,882
BRAYTON-CAES (Below Ground)	S9 - 2	103	8.0	824	74%	\$1,053	\$132	\$934	\$15	\$5	\$0.0035	\$130	\$379	\$611	\$4,885
BRAYTON-CAES (Below Ground)	S9 - 1	103	20.0	2,060	74%	\$1,129	\$141	\$921	\$26	\$5	\$0.0035	\$133	\$390	\$627	\$5,020
BRAYTON-CAES (Below Ground)	S9 - 2	103	20.0	2,060	74%	\$1,142	\$143	\$934	\$26	\$5	\$0.0035	\$134	\$390	\$628	\$5,022
BRAYTON-CAES (Below Ground)	S9 - 1	136	8.0	1,088	75%	\$1,050	\$131	\$918	\$17	\$5	\$0.0035	\$130	\$380	\$612	\$4,894
BRAYTON-CAES (Below Ground)	S9 - 2	136	8.0	1,088	74%	\$1,065	\$133	\$933	\$17	\$5	\$0.0035	\$130	\$381	\$613	\$4,903
BRAYTON-CAES (Below Ground)	S9 - 1	136	20.0	2,720	75%	\$1,129	\$141	\$921	\$26	\$5	\$0.0035	\$133	\$390	\$627	\$5,020
BRAYTON-CAES (Below Ground)	S9 - 2	136	20.0	2,720	74%	\$1,142	\$143	\$934	\$26	\$5	\$0.0035	\$134	\$390	\$628	\$5,022

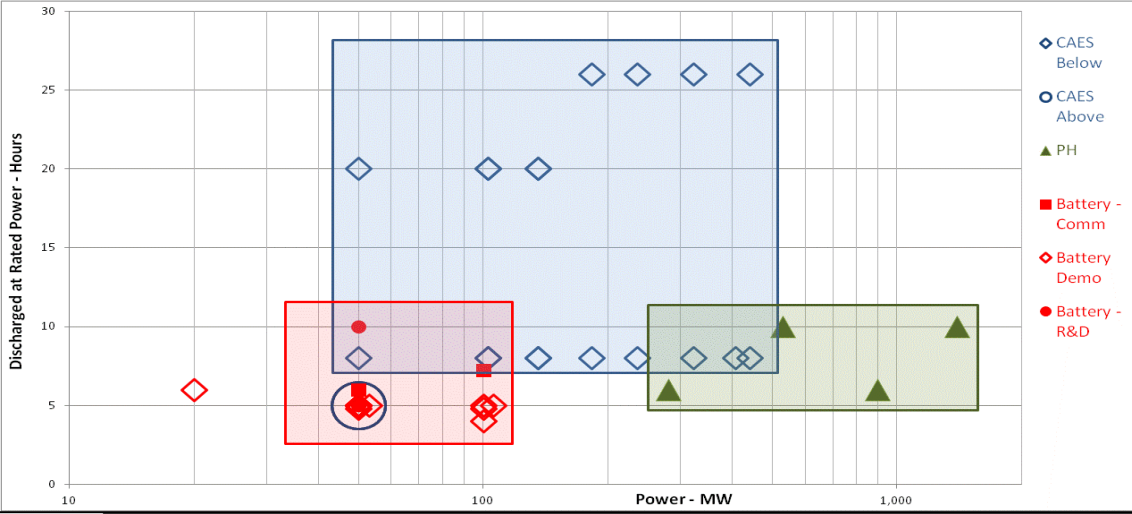
Technology Type	Supplier	Unit Capacity Gross MW	Storage Hrs	Capacity MWh	AC Eff. %	Cycles /year	Batt. Repl. yrs	Total Equip. Cost \$/kW	Total Equip. Cost \$/kWh	Power Comp. \$/kW	Storage Comp. \$/kWh	Fixed O&M \$/kW-yr	Variable O&M \$/kWh	LCOE \$/MWh	LCOE \$/kW-Yr	PV Inst. Cost \$/kW	PV Inst. Cost \$/kW
BRAYTON-CAES (Below Ground)	S9	408	8.0	3,264	74%	365	15	\$3,071	\$512	\$516	\$426	\$4	\$0.0005	\$294	\$644	\$959	\$5,753
BRAYTON-CAES (Below Ground)	S9	408	20.0	8,160	74%	365	15	\$3,168	\$440	\$490	\$372	\$4	\$0.0004	\$260	\$684	\$849	\$6,109
Pumped Hydro	N/A	280	6.0	1,680	81%	365	15	\$3,071	\$512	\$516	\$426	\$4	\$0.0005	\$294	\$644	\$959	\$5,753
Pumped Hydro	N/A	530	10.0	5,300	81%	365	15	\$3,168	\$440	\$490	\$372	\$4	\$0.0004	\$260	\$684	\$849	\$6,109
Pumped Hydro	N/A	900	6.0	5,400	81%	365	15	\$3,071	\$512	\$516	\$426	\$4	\$0.0005	\$294	\$644	\$959	\$5,753
Pumped Hydro	N/A	1,400	10.0	14,000	81%	365	15	\$3,168	\$440	\$490	\$372	\$4	\$0.0004	\$260	\$684	\$849	\$6,109

Technical Maturity: Commercial Stage																	
CT-CAES (Above Ground)	S12 - 2	50	5.0	250	45%	365	8	\$5,876	\$979	\$796	\$847	\$6	\$0.0005	\$549	\$1,203	\$1,792	\$10,753
CT-CAES (Above Ground)	S0	50	5.0	250	81%	365	8	\$1,743	\$349	\$507	\$247	\$4	\$0.0005	\$226	\$413	\$739	\$3,693
CT-CAES (Above Ground)	S12 - 1	50	5.0	250	70%	365	8	\$2,287	\$476	\$527	\$367	\$4	\$0.0006	\$292	\$512	\$954	\$4,578
CT-CAES (Below Ground)	S12	50	8.0	400	70%	365	8	\$4,809	\$962	\$634	\$835	\$4	\$0.0005	\$537	\$980	\$1,751	\$8,756
CT-CAES (Below Ground)	S12	50	26.0	1,300	70%	365	8	\$4,897	\$979	\$663	\$847	\$4	\$0.0005	\$549	\$1,002	\$1,792	\$8,959
CT-CAES (Below Ground)	S12	183	8.0	1,464	70%	365	8	\$2,254	\$470	\$494	\$367	\$4	\$0.0006	\$289	\$506	\$943	\$4,527
CT-CAES (Below Ground)	S12	183	26.0	4,758	70%	365	8	\$4,326	\$1,082	\$546	\$945	\$4	\$0.0007	\$599	\$875	\$1,954	\$7,818
CT-CAES (Below Ground)	S12	322	8.0	2,576	70%	365	15	\$2,823	\$565	\$487	\$467	\$4	\$0.0005	\$312	\$569	\$1,018	\$5,089
CT-CAES (Below Ground)	S12	322	26.0	8,372	70%	365	8	\$4,306	\$861	\$427	\$776	\$4	\$0.0005	\$490	\$895	\$1,600	\$7,998
CT-CAES (Below Ground)	S12	441	8.0	3,528	70%	365	8	\$5,334	\$1,067	\$482	\$970	\$5	\$0.0005	\$597	\$1,089	\$1,947	\$9,734
CT-CAES (Below Ground)	S12	441	26.0	11,466	70%	365	8	\$3,734	\$747	\$635	\$620	\$4	\$0.0005	\$434	\$792	\$1,415	\$7,077
						365	15	\$1,674	\$335	\$484	\$238	\$4	\$0.0005	\$226	\$413	\$737	\$3,687
						365	15	\$1,641	\$328	\$451	\$238	\$4	\$0.0005	\$223	\$407	\$727	\$3,635

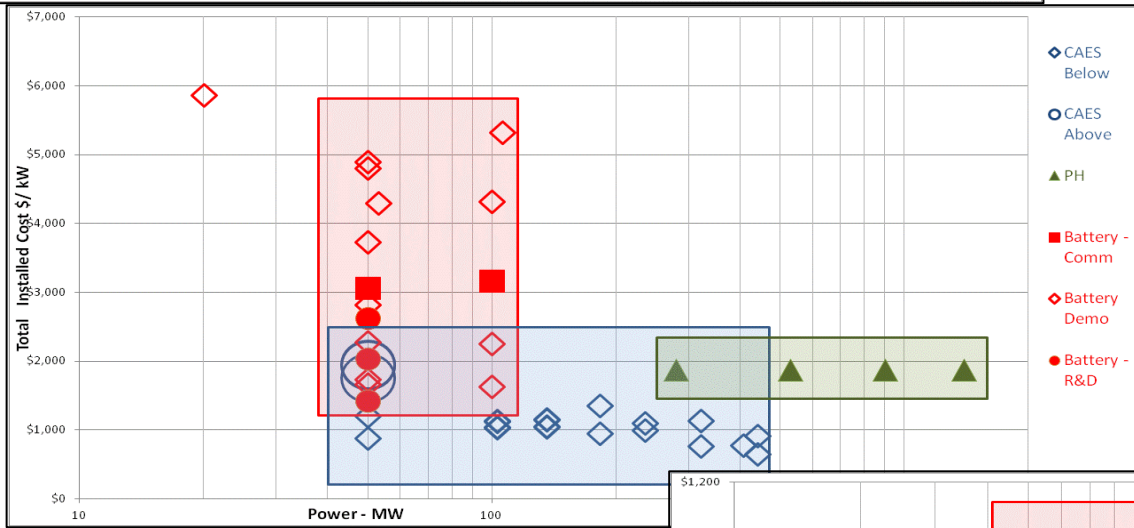
Technical Maturity: Demonstration Stage																	
Adv. Lead Acid	S15	20	6.0	120	90%	365	8	\$1,743	\$349	\$507	\$247	\$4	\$0.0005	\$226	\$413	\$739	\$3,693
Adv. Lead Acid	S13	50	5.0	250	85%	365	8	\$2,287	\$476	\$527	\$367	\$4	\$0.0006	\$292	\$512	\$954	\$4,578
Adv. Lead Acid	S11	50	5.0	250	90%	365	8	\$4,809	\$962	\$634	\$835	\$4	\$0.0005	\$537	\$980	\$1,751	\$8,756
Adv. Lead Acid	S15	50	5.0	250	90%	365	8	\$4,897	\$979	\$663	\$847	\$4	\$0.0005	\$549	\$1,002	\$1,792	\$8,959
Adv. Lead Acid	S44	100	4.8	480	85%	365	8	\$2,254	\$470	\$494	\$367	\$4	\$0.0006	\$289	\$506	\$943	\$4,527
Adv. Lead Acid	S11	100	4.0	400	90%	365	8	\$4,326	\$1,082	\$546	\$945	\$4	\$0.0007	\$599	\$875	\$1,954	\$7,818

Technical Maturity: R&D Stage																	
Aqueous Hybrid Ion	S4	50	5.0	250	83%	365	8	\$2,630	\$526	\$530	\$420	\$4	\$0.0005	\$318	\$579	\$1,036	\$5,179
Fe / Cr	S14	50	5.0	250	75%	365	8	\$1,427	\$285	\$455	\$194	\$4	\$0.0005	\$197	\$360	\$643	\$3,213
Fe / Cr	S14	50	10.0	500	75%	365	8	\$2,045	\$205	\$485	\$156	\$4	\$0.0003	\$154	\$563	\$503	\$5,031
Zn / Air	S20	50	6.0	300	80%	365	15	\$1,428	\$238	\$443	\$164	\$4	\$0.0005	\$164	\$359	\$534	\$3,205

Battery Systems

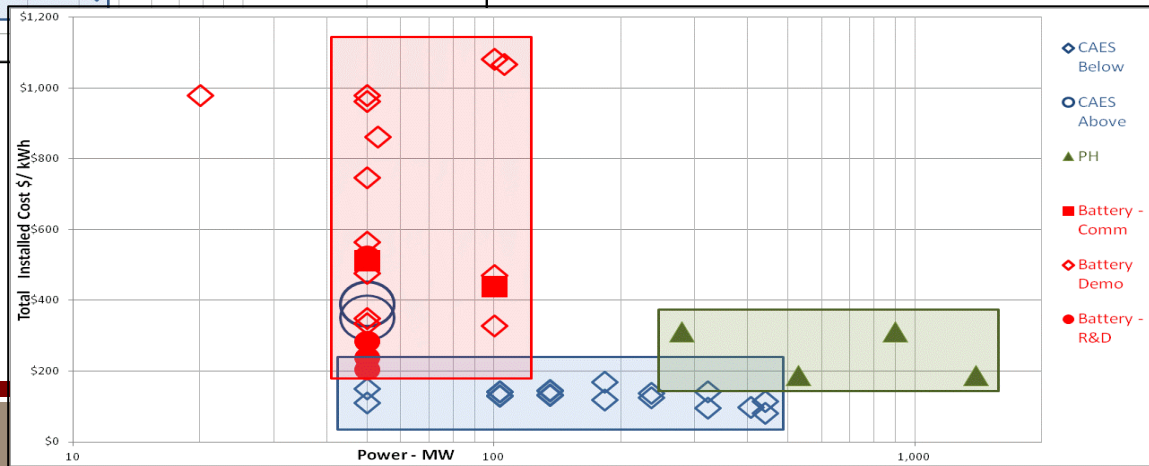


Energy vs Power

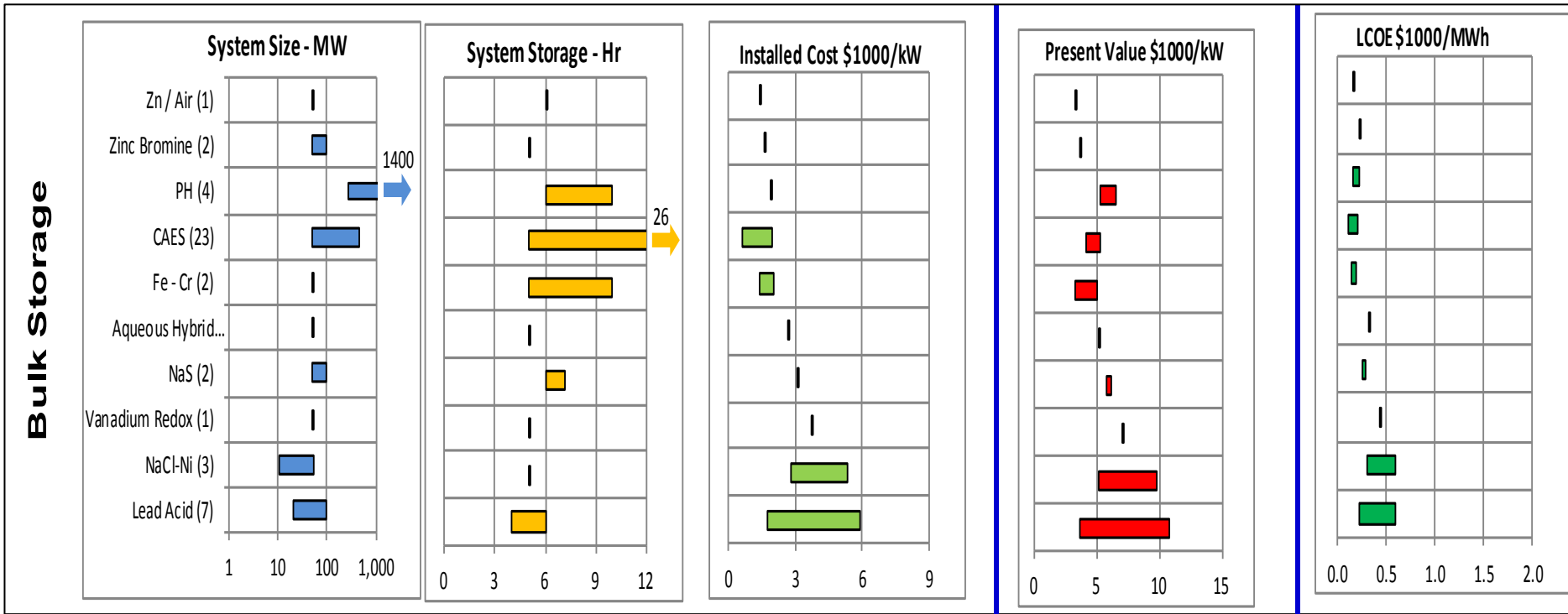


\$/kW vs Power

\$/kWh vs Power



Summary Cost Charts - Detail



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**

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