III. R&D Activities, Technology, and Cost Considerations

Instructor – John Boyes, Sandia National Lab

- **Energy Storage R&D**
  - **US Department of Energy**
  - **California Energy Commission (CEC)**
  - **Electricity Storage Association (ESA)**
  - **EPRI**
- **Life Cycle Cost Analysis and Capital Cost – Benefit Comparison**

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Why Energy Storage?

Energy Storage Mediates Between

Variable Sources and Variable Loads

DOE Energy Storage Program

- Develop advanced electricity storage technologies, in partnership with industry, for modernizing and expanding the electric supply.

- This will improve the quality, reliability, flexibility and cost effectiveness of the existing system.

Benefits of Energy Storage

- Transmission & Distribution
  - Line and Transformer Deferral
  - Stability
  - Voltage Regulation
- End-Use
  - Power Quality/Reliability
  - Peak Load Reduction
  - Distributed Generation Support
- Generation
  - Spinning Reserve
  - Capacity Deferral
  - Area/Frequency Regulation
  - Load Leveling
  - Renewables Support

ESS Program Scope

Broad Technology Base

- Batteries
- Controls
- Flywheels
- Power Electronics
- SMES
- Ultracapacitors

Applications Focus

- Power Quality
- Distributed Resources
- Peak Shaving
- Renewable Generation

	POWER Applications		ENERGY Applications
LOAD	**PQ, Digital Reliability**	**DER Support for Load Following**	**Peak Shaving to Avoid Demand Charges**
GRID	**Voltage Support, Transients**	**Dispatchability for Renewables, Village Power**	**Mitigation of Transmission Congestion, Arbitrage**
	seconds	**minutes**	**hours**

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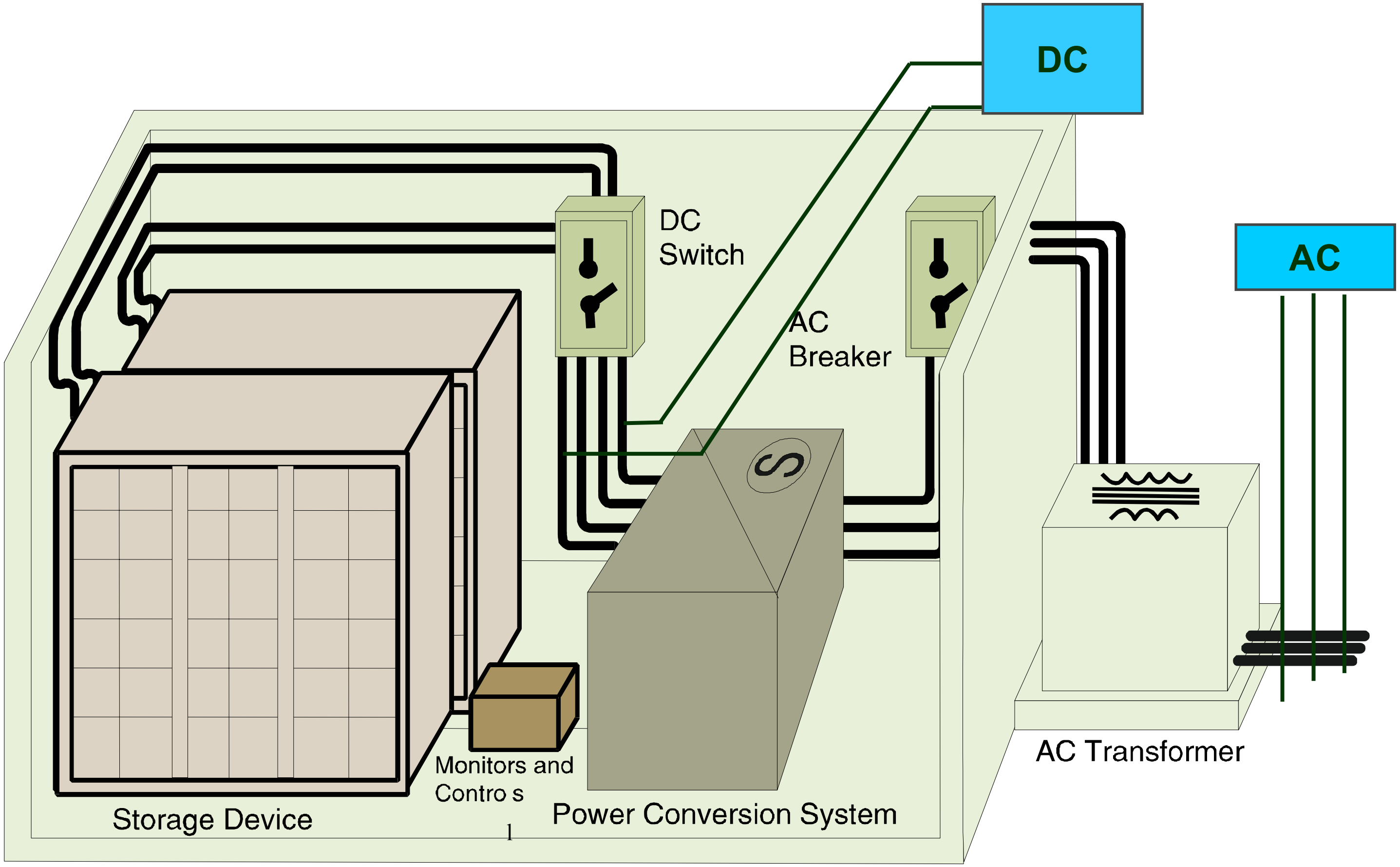
Electricity Energy Storage System



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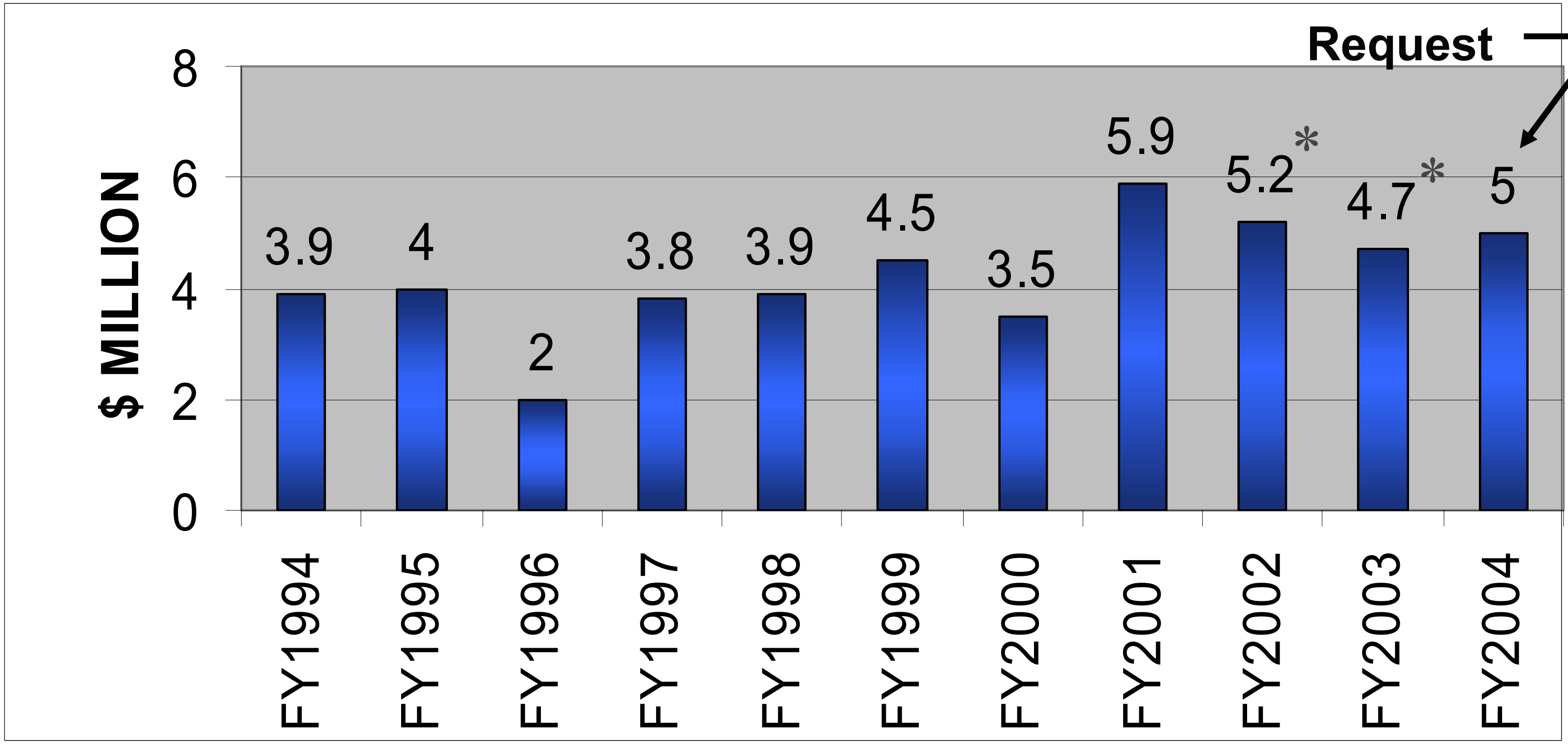
Energy Storage Systems Program Goals

- Develop and evaluate integrated energy storage systems
- Develop batteries, SMES, flywheels, electrochemical capacitors and other advanced energy storage devices
- Improve multi-use power electronics, controls, and communications components
- Analyze and compare technologies and application requirements
- Encourage program participation by industry, academia, research organizations and regulatory agencies

DOE/ESS Program Elements

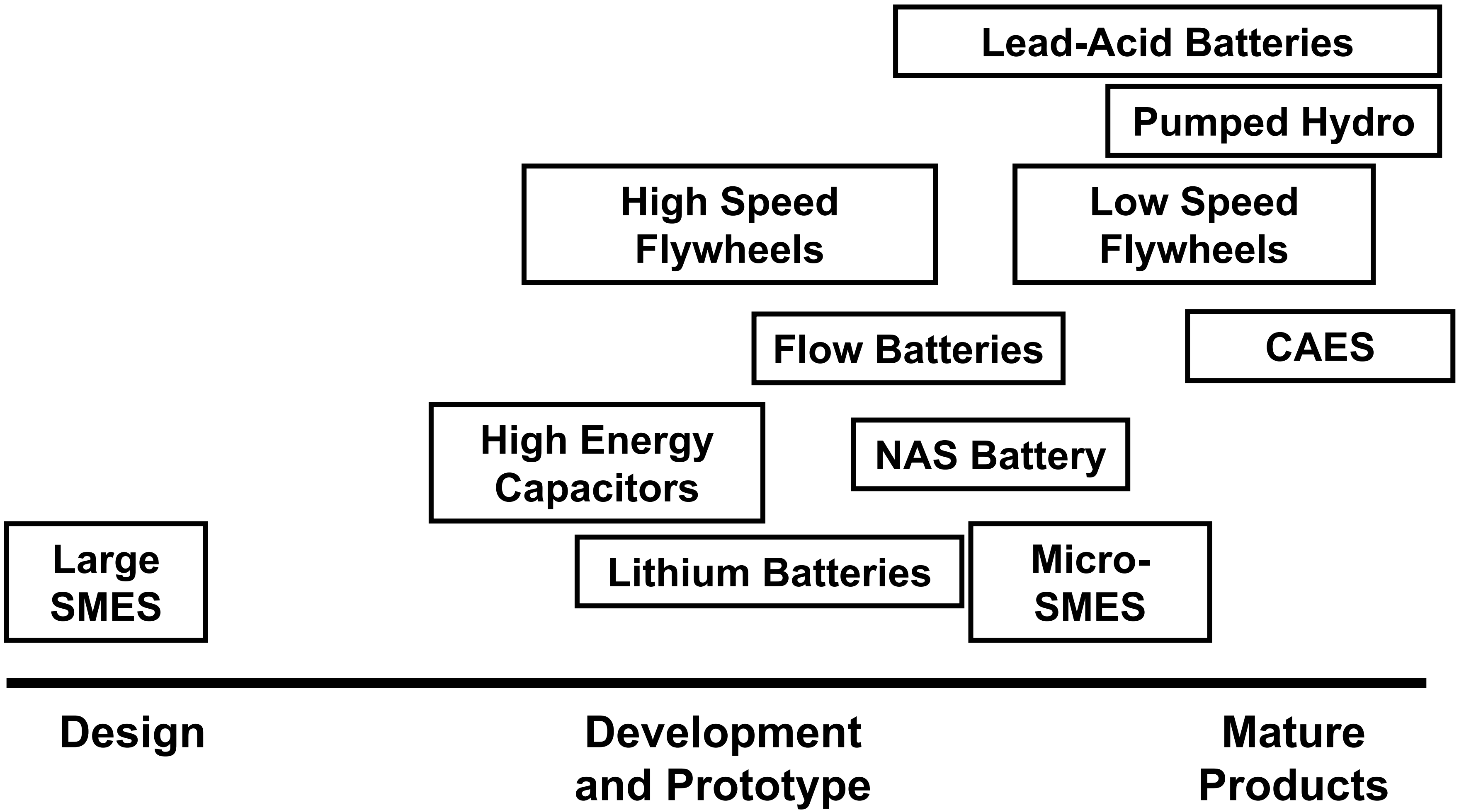
- System Integration
  - pursues a strategy to reduce the inefficient, one-of-a-kind system engineering historically required when utility energy storage systems have been designed and built
  - evaluate and disseminate information on systems in the field
- Subsystem Development - develop and evaluate the components of the energy storage system to achieve lower cost, higher performance, and better integration than currently available.
  - storage component (e.g., flywheel, battery, electrochemical capacitors or SMES)
  - power conversion and control subsystems
- Strategic Research - formulation and application of analytical methodologies necessary to identify utility applications and estimate the technical and economic benefits of energy storage.

DOE Energy Storage Systems Program Funding



* After earmarks

Commercial Maturity of Storage Technologies



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Recent Program Highlights

- Two R&D 100 Awards for program projects
  - ETO high power electronic switch – Solitronics, Virginia Polytechnic Institute, DOE/ESS, Sandia, American Competitiveness Institute
  - Fiber optic current sensor – Airak Inc., DOE/ESS
- Partnerships formed with TVA and AEP to monitor and analyze data from a Regenesys and a NAS system
- ETO – High Power testing initiated in collaboration with the Naval Surface Weapons Center in Philadelphia

Recent Program Highlights

- Li-ion BESS completed factory system testing and installed at Southern Co. for field testing
- Partnership formed with California Energy Commission for an Energy Storage Initiative
- Study using PJM data shows that potential for energy storage systems is in the GWs
- EESAT 2002 Conference
  - 165 Attendees from 13 countries

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DOE ESS Success Story
12.5 MVA Purewave® UPS

- S&C Electric Company
- STMicroelectronics wafer fabrication plant Phoenix, Arizona
- Installed in utility substation

- **45 operations since August, 2000** **(8/02)**
- **System cost US$ 300/kVA**

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Vernon BESS
GNB Industrial Power

Critical Load Backup

Energy Management

- Lead Smelter:
  Battery Recycling
- Near Los Angeles, CA
- 5 MW, 3.5 MWH VRLA Battery
- 1996 Commissioning

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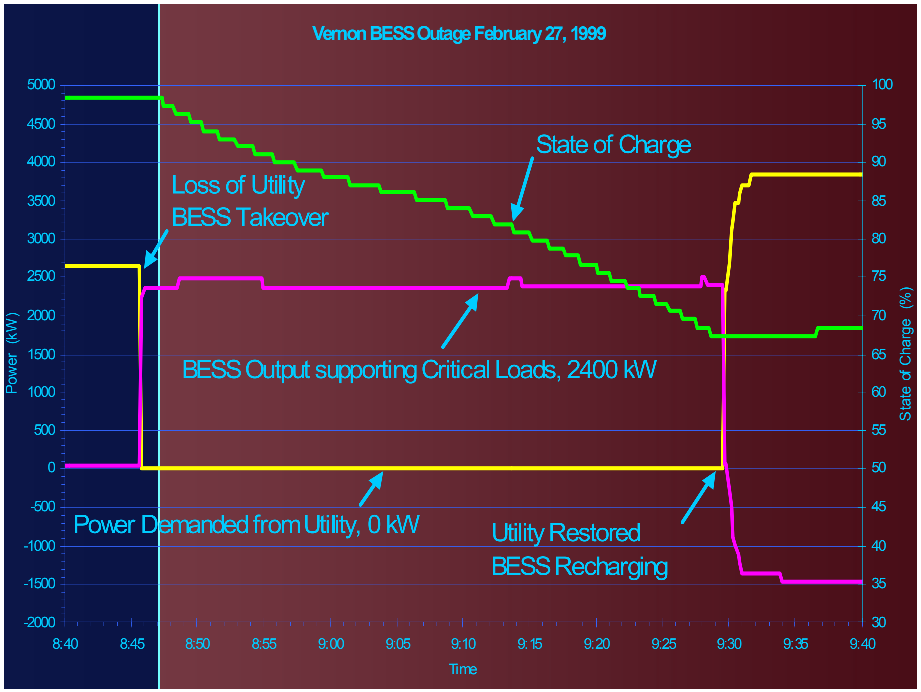
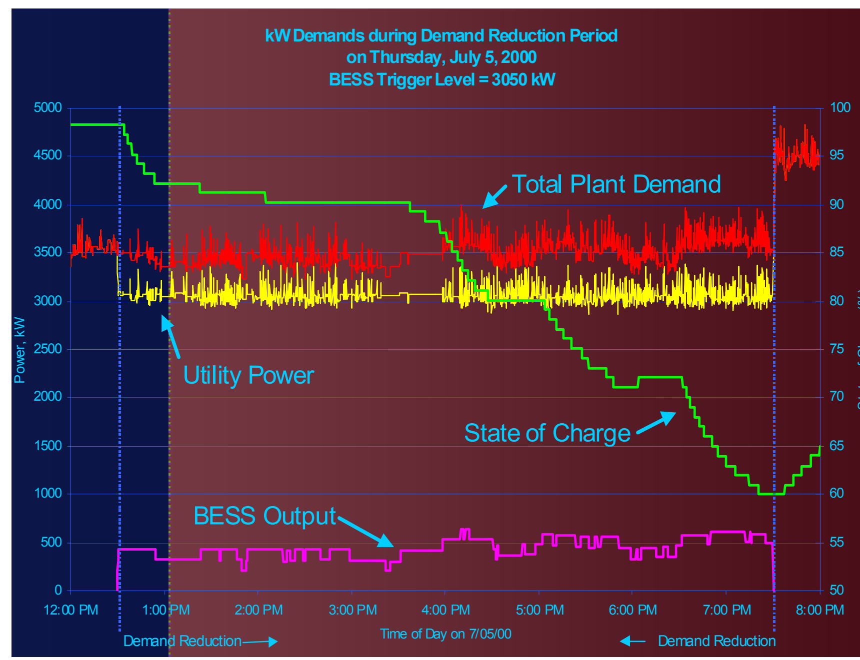
Vernon BESS Performance



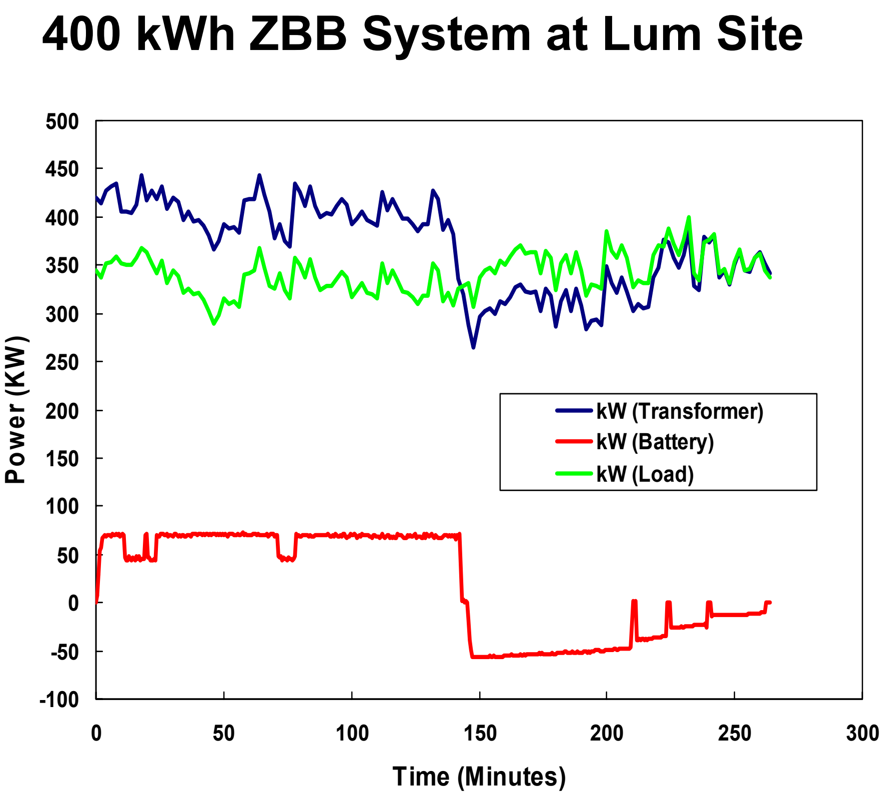
Power Quality
45 Minute Utility Outage

Energy Management
500-600 kW
Peak Shaving



400 kWh Zinc Bromine BESS

ZBB Inc.
Detroit Edison



- **Demonstrated Interconnection to utility**
- **Demonstrated ability on automatically control in peak shaving**
- **Invited back next summer**

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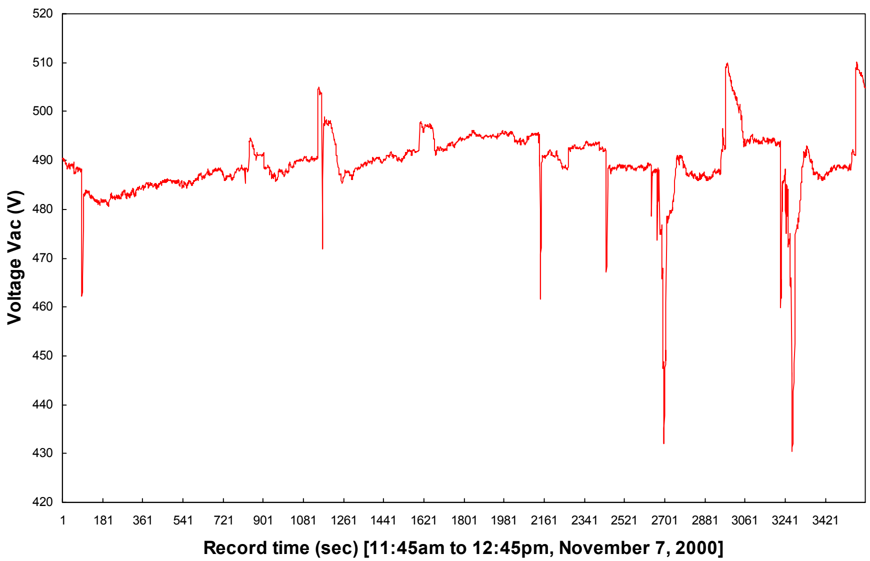
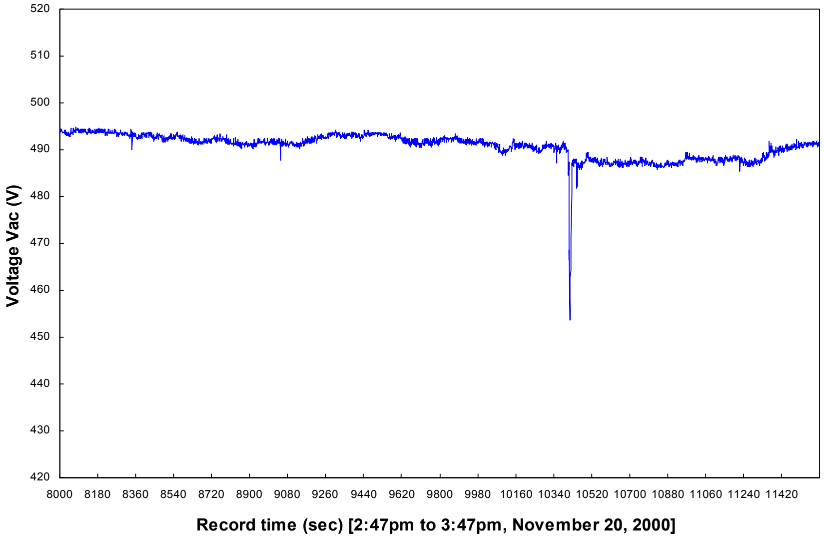
ZBB Power Quality Application



Akron MI, Grain Dryer Site



- Reduced voltage drop due to 75 hp motor starts
- Eliminated spikes as dryer turns off

Lithium Batteries

Lithium Battery modules

100 kW – 1 minute SAFT Li-ion battery with Satcon PCS for DER-Microturbine application

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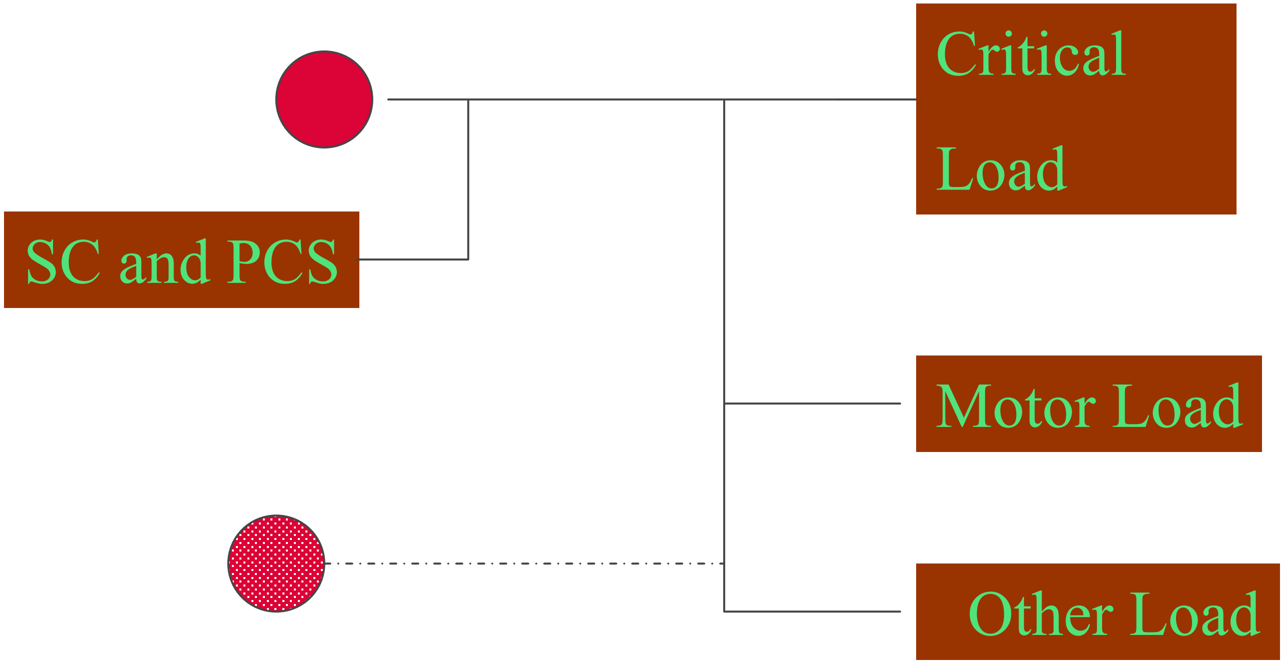
Electrochemical Capacitors

- EC capacitors offer the potential of very high power density and high cycle lifetimes
- Applications include all high power applications
  - Transmission stability
  - Power quality
  - Distributed resource support
- Microturbine stand alone load following
  - Current surges (e.g. motor starts) can trip a microturbine

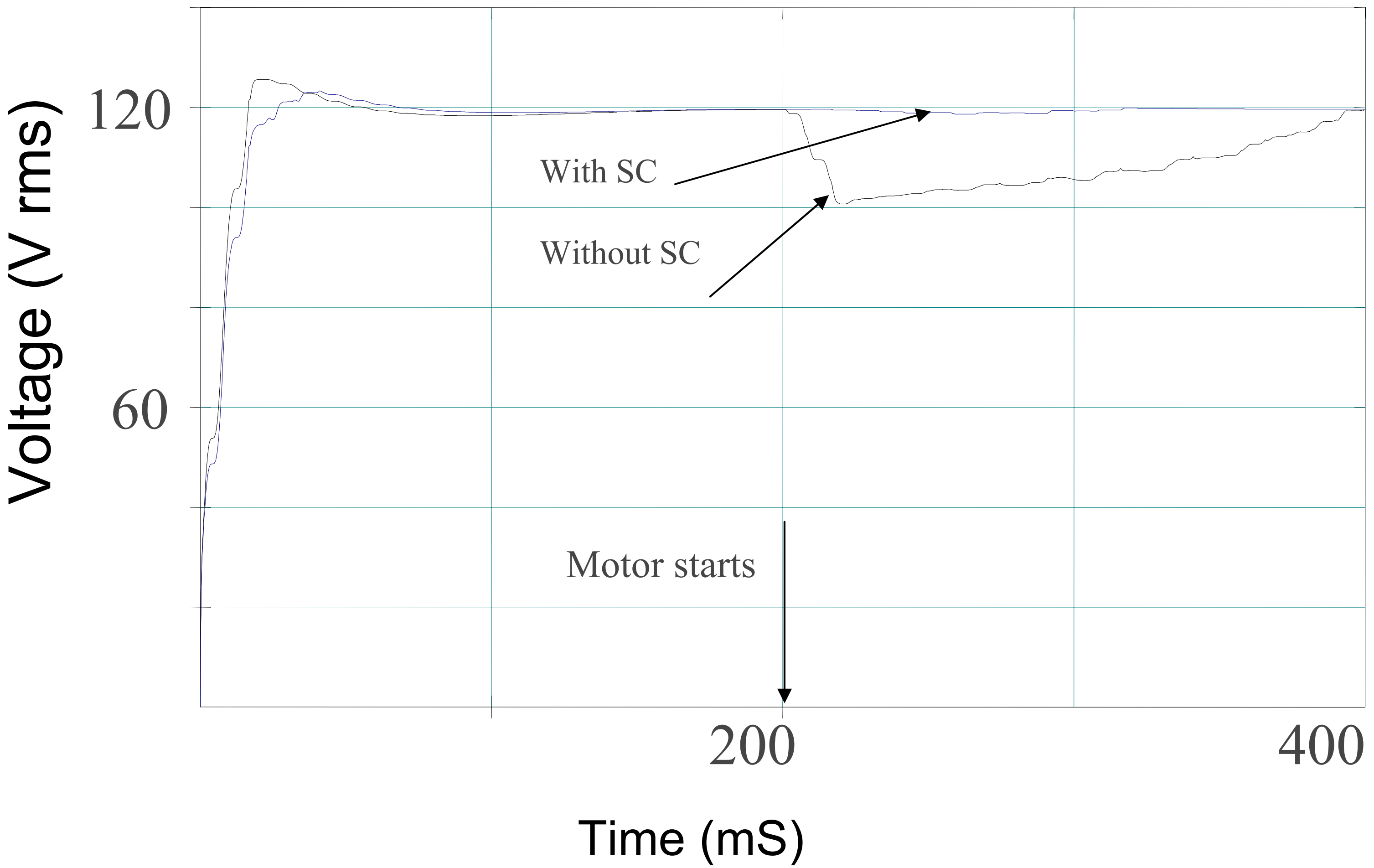
Possible Solutions to Motor Start Problem

- Proposed-- DER Side



SC provides supplementary current to sustain DER

Proposed Approach



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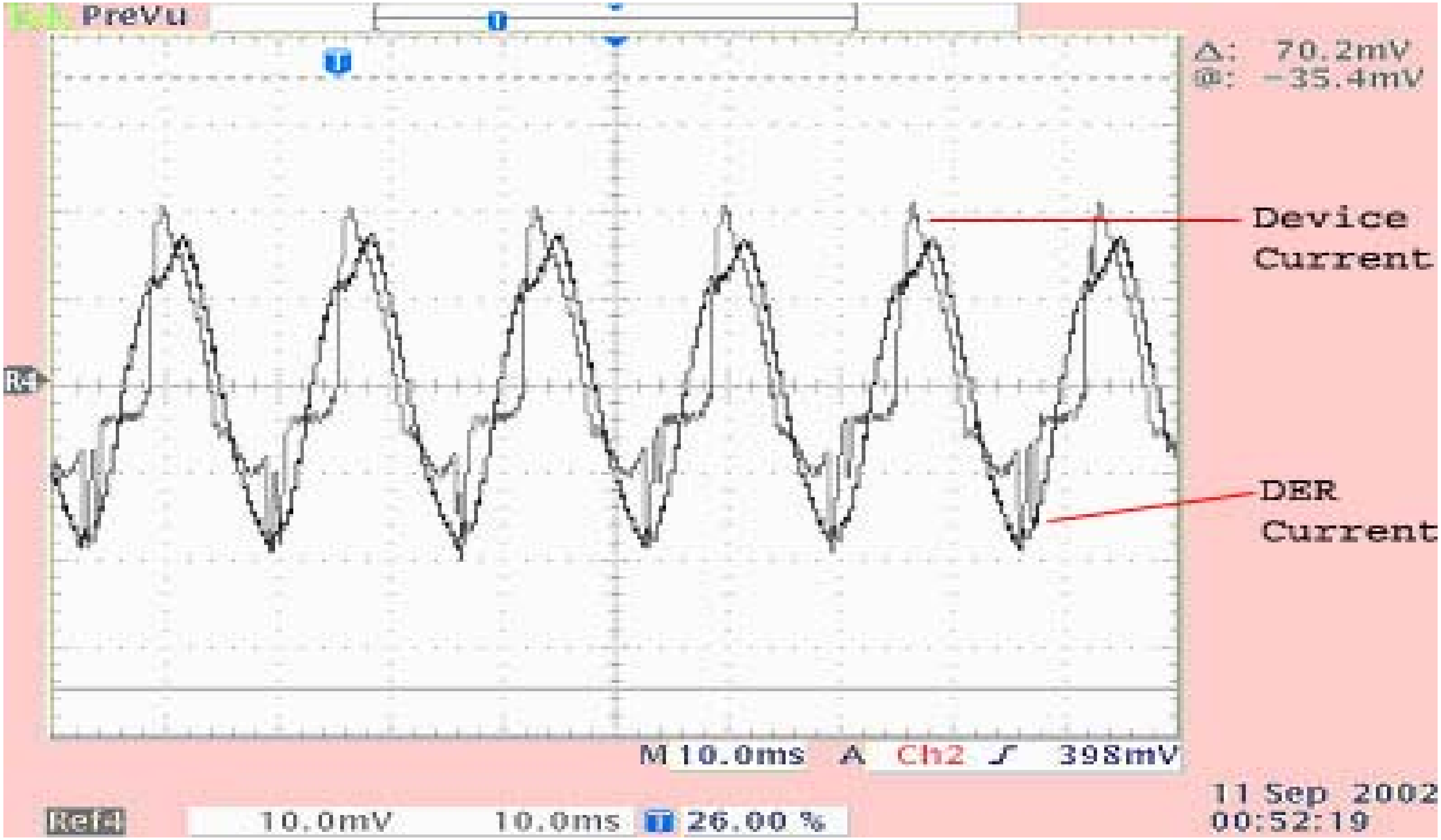
Experimental Results



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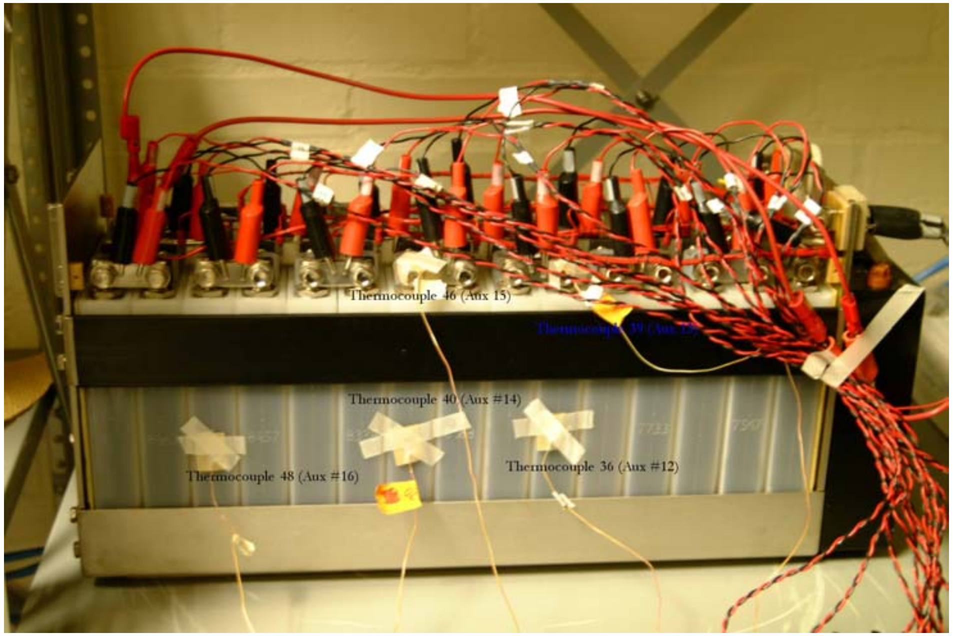
Sandia Testing of EC Capacitors

ESMA EC Capacitor and Experimental PEAC PQ System



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Regenesys Monitoring with TVA

- •120 MWh Regenesys® electrical energy storage system
- •Peak Shaving – 12 MW for 10 hours

100 kW Regenesys Module

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NAS Battery Monitoring with AEP

- 2 NGK Insulators Ltd., NAS™ battery modules
- 300 kW of PQ protection for 30 seconds
- 100 kW of peak shaving capacity for 7 hours
- AEP site, in Gahanna OH.

NGK INSULATORS, LTD.

50kW SUPER POWER NAS BATTERY DESIGN AND PERFORMANCE

Pulse Power	250kW (30 seconds)
Rated Power	50kW
Energy	360kWh
Dimensions	2200W ×1762D ×640H [mm]
Weight	3600kg

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Flywheels

- Low Speed (steel) flywheels are commercially available for power quality applications (Pillar, Caterpillar, Active Power)
- High speed (composite) flywheels are entering commercial products (Urenco, Beacon, …) or in development (Boeing, AFS Trinity, …)
- Flywheels promise lower maintenance, longer life, higher power density, and higher efficiency than conventional batteries

Superconducting Flywheel Development
Boeing Phantom Works

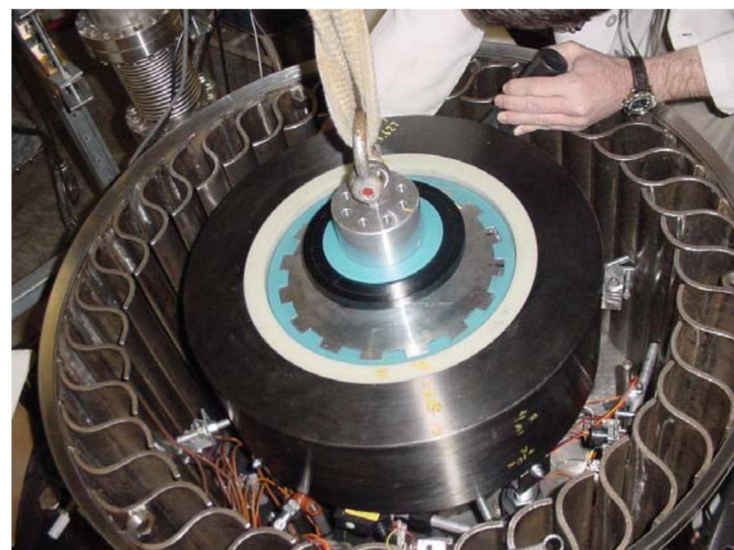
Joint Project with Superconducting Project Initiative

Advantages of Superconducting Bearings

Much lower frictional losses No electronic bearing controls required
Simple bearing design
Passive control for greater reliability and life
Lower weight, cost, and maintenance

ESS Project Goals

- Develop low-cost rotor/bearing
- Determine & enhance system reliability



Power Electronics

- Power Electronic System is >25% of system cost
- Power Electronic Systems do not have the desired reliability
- Power Conversion from storage to/from desired output contributes significantly to system size, complexity and design tradeoffs
- ETO – High power, fast switching speed
  - collaboration with
    - Navy NSWC
    - ACI
    - TVA
    - Virginia Tech

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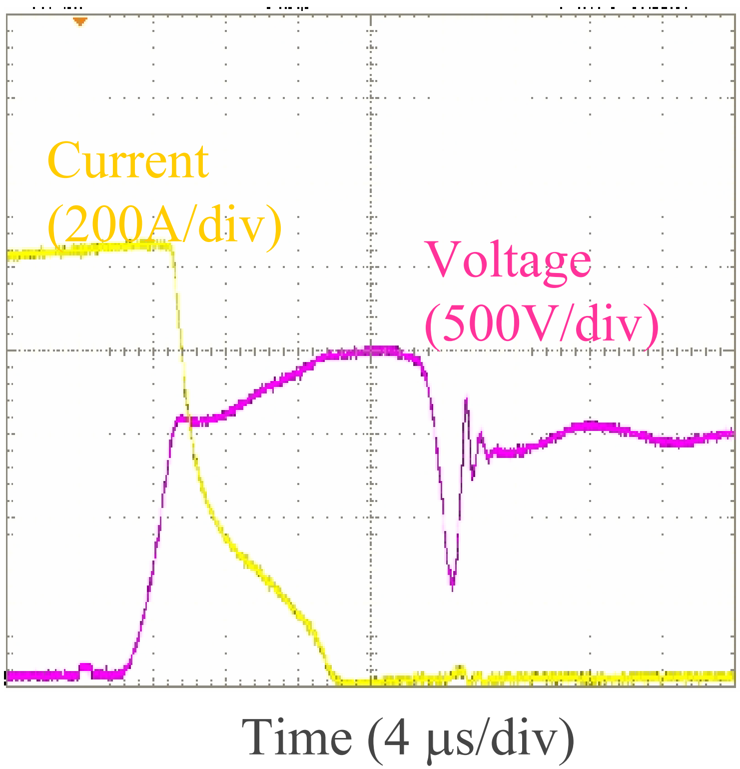
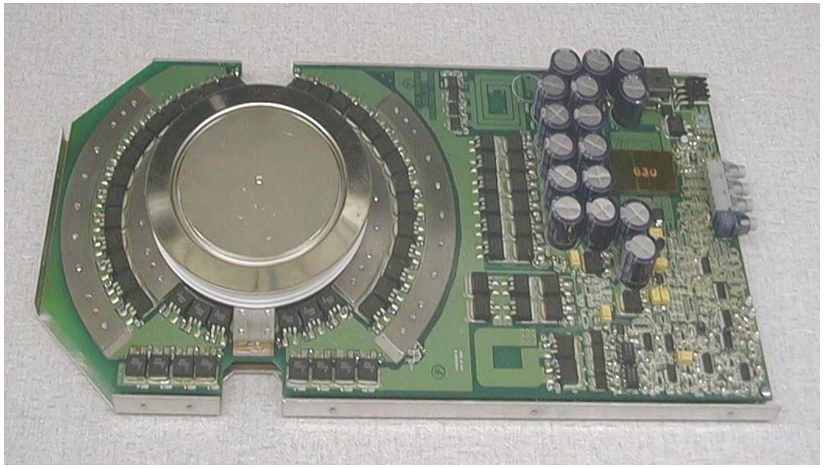
Emitter Turn-off (ETO) Thyristor Development

Dr. Alex Q. Huang

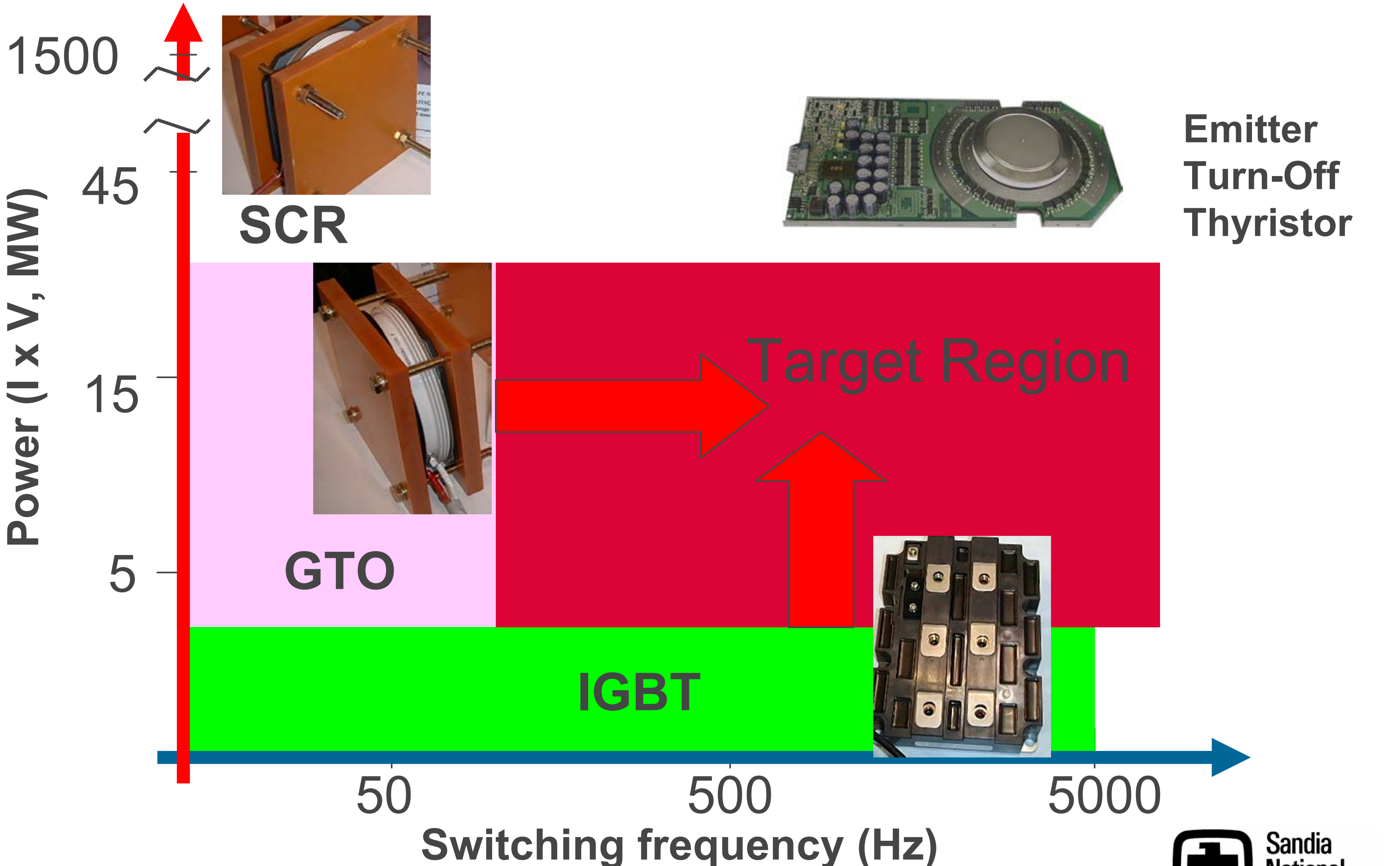
Center for Power Electronics Systems, Virginia Tech





Gen-3 ETO Prototype

Power Electronic Devices (High Power)



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Electric Vehicle – Stationary Systems

- Study completed on secondary usage of EV batteries in stationary applications.
- Concept is viable
- Possible applications include transmission support, telecom, light commercial and residential load following, (assuming the growth of distributed generation for residential)
- Hurdles include
  - Lack of infrastructure for acquiring, testing, reconfiguring batteries
  - Difficulties in configuring individual battery systems into large scale assemblies
  - Uncertain remaining lifetime
  - Uncertain economics

Technical and Economic feasibility of Applying Used EV Batteries in Stationary Applications, Cready et. al., SAND2002-4084

http://infoserve.sandia.gov/sand_doc/2002/024084.pdf

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Benefit calculations and potential market

- DOE has conducted several Energy Storage Opportunities, Applications and Benefits studies
- DOE in collaborating with the California Energy Commission in a energy storage procurement
- DOE wrote "Benefits and Market Analysis Handbook", Appendix 14, for the CEC RFP
  - Methodology for calculating economic benefit of storage system in California market
  - Estimated market potential for 15 applications in California
  - www.energy.ca.gov/contracts

California Benefits and Market Potential

Application/Benefit	Discharge Duration* Minimum	Discharge Duration* Highest	Lifecycle Financial Benefits ($/kW)	Maximum Market Potential (MW)	Ten-year Economic Benefits ($Million)**
Bulk Electricity Price Arbitrage	1	10	200 to 300	735	147 to 220
Distribution Upgrade Deferral 50th Percentile of Benefits	2	6	666	804	536
Distribution Upgrade Deferral 90th Percentile of Benefits	2	6	1,067	161	172
Transmission Upgrade Deferral	4	6	650	1,092	710
T&D Congestion Relief	2	6	72***	3,200	230
Customer Time-of Use Energy Cost Management	2 Seconds	5 Seconds	82	1,000	82
Customer Demand Charge Management	6	11	465#	4,005	1,862

*Hours unless other units are specified.

**Over ten years, based on lifecycle benefits times maximum market potential (market estimates will be lower).

***Placeholder values. The actual benefit was not estimated.

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California Benefits and Market Potential

Application/Benefit	Discharge Duration* Minimum	Discharge Duration* Highest	Lifecycle Financial Benefits ($/kW)	Maximum Market Potential (MW)	Ten-year Economic Benefits ($Million)**
End-user Electric Service Reliability	.25	5	359	4,005	1,438
Renewables Capacity firming	6	10	172##	1,800	310
Renewables Contractual Time-of-Production Payments	6	11	651##	500	326
T.O.U.Energy Rates Plus Demand Charge Reduction	6	11	866	4,005	3,468

*Hours unless other units are specified.

**Over ten years, based on lifecycle benefits times maximum market potential (market estimates will be lower).

***Placeholder values. The actual benefit was not estimated.

#Does not include incidental energy-related benefit.

##Wind generation.

NOTE: Benefits listed that are not applications are: 1. Avoided Electric Supply Capactiy Cost, 2. Ancillary Service, 3. Avoided Transmission Access Charges, and 4. Avoided Power Quality-related Cost.

California Benefits and Market Potential

Application/Benefit	Discharge Duration* Minimum	Highest	Lifecycle Financial Benefits ($/kW)	Maximum Market Potential (MW)	Ten-year Economic Benefits ($Million)**
Avoided Central Generation Capacity Cost	4	6	215	3,200	688
Ancillary Services	1	5	72***	800	58
Avoided Transmission Access Charges	1	6	72***	3200	230
Reduced PQ-related Financial Losses	10 seconds	1 Minute	717	4,005	2,872

*Hours unless other units are specified.

**Over ten years, based on lifecycle benefits times maximum market potential (market estimates will be lower).

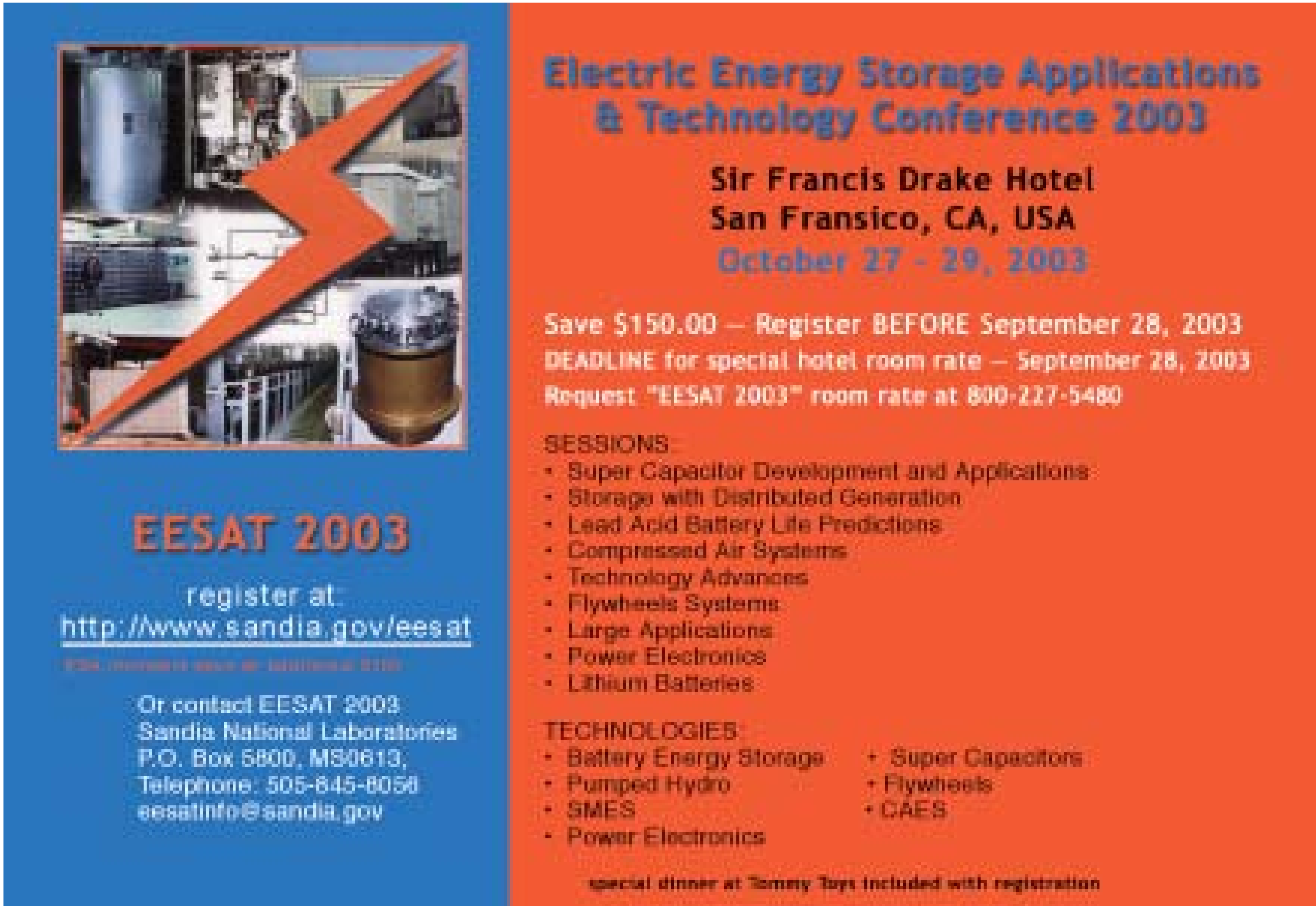
***Placeholder values. The actual benefit was not estimated.

#Does not include incidental energy-related benefit.

##Wind generation.

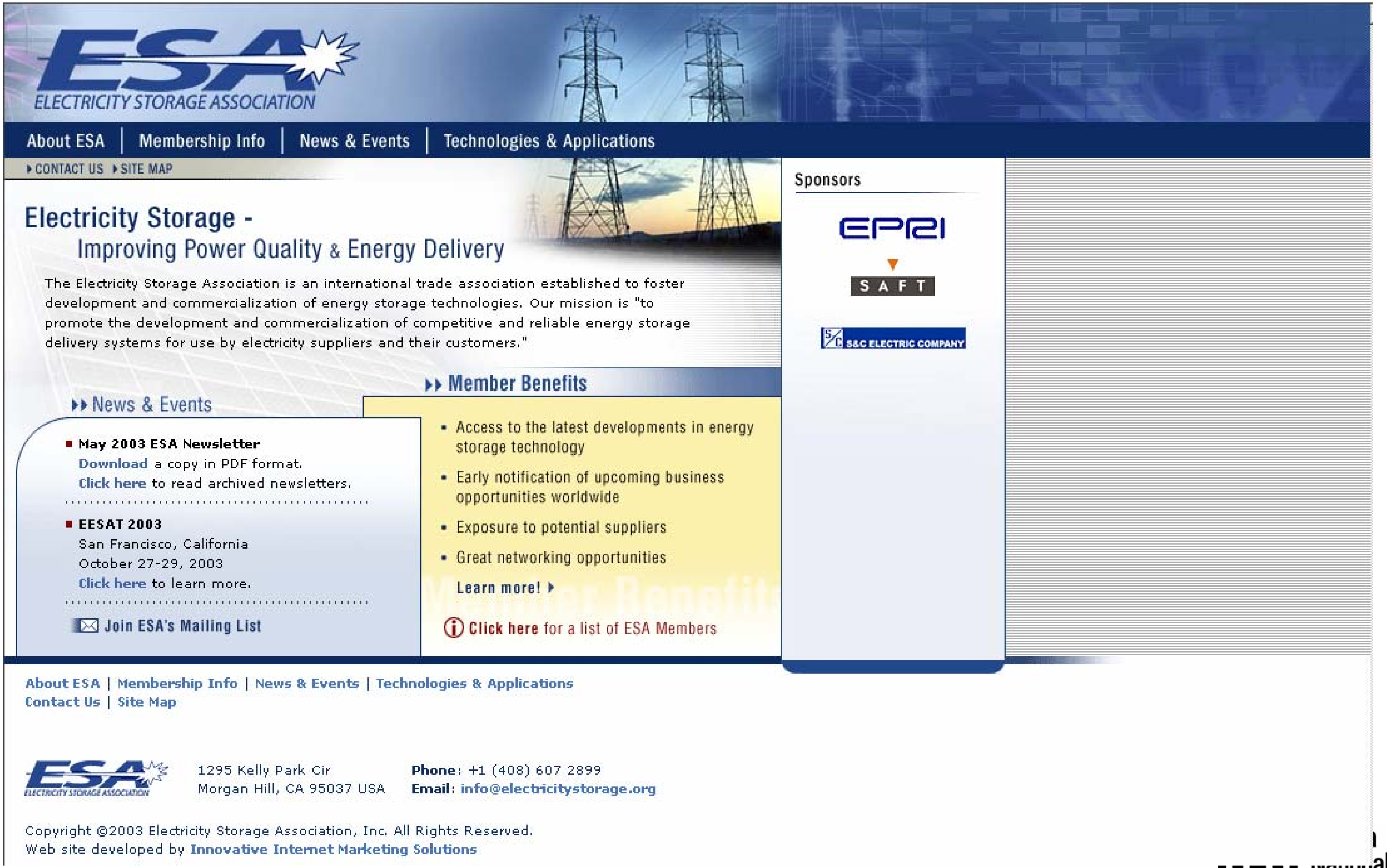
NOTE: Benefits listed that are not applications are: 1. Avoided Electric Supply Capactiy Cost, 2. Ancillary Service, 3. Avoided Transmission Access Charges, and 4. Avoided Power Quality-related Cost.

EESAT 2003 Conference
http://www.sandia.gov/eesat

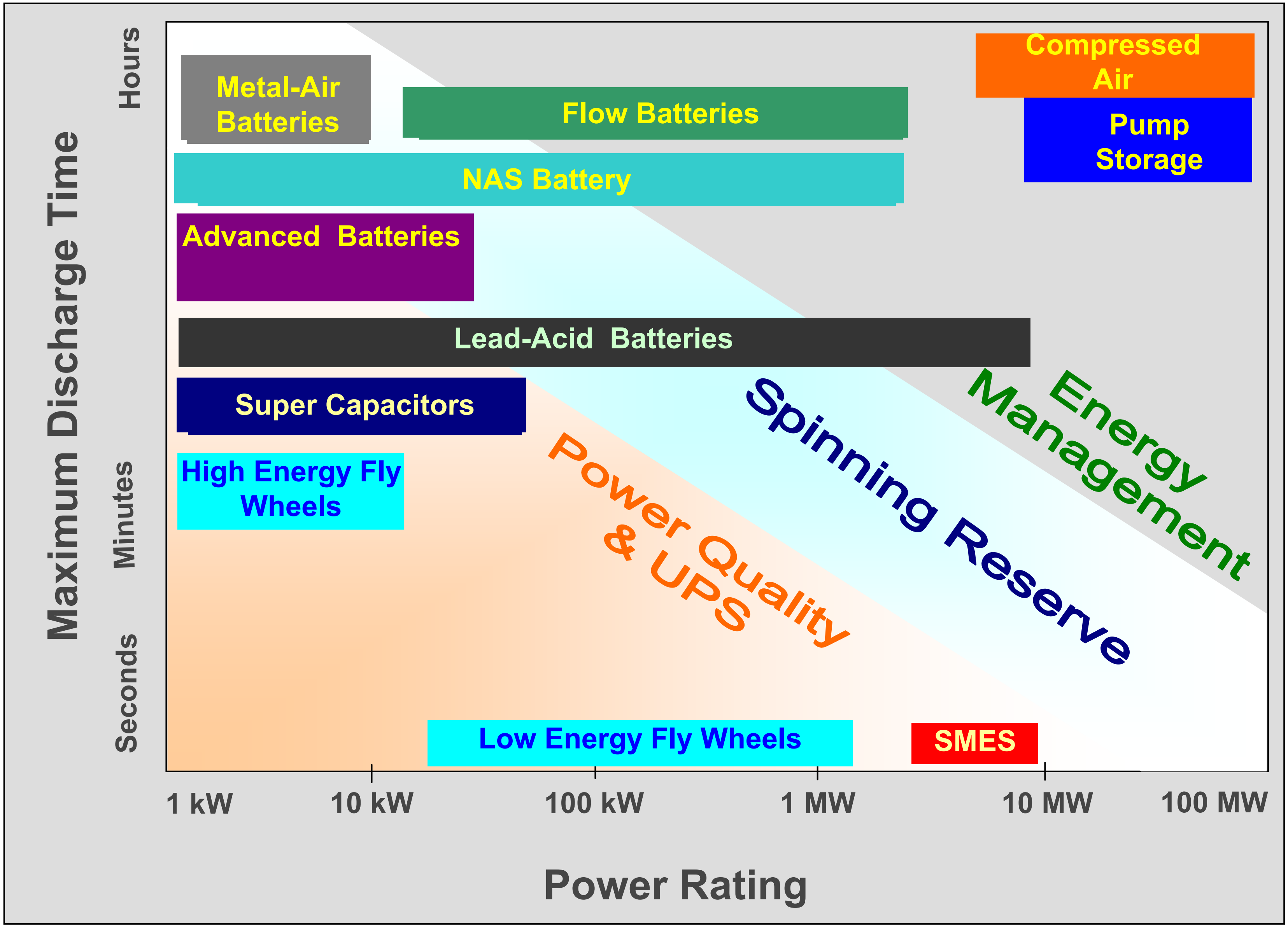


http://www.sandia.gov/eesat

Electricity Storage Association
www.electricitystorage.org



Electricity Storage Association



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ESA Table on advantages and disadvantages of various technologies

Storage Technologies	**Main Advantages** (relative)	**Disadvantages** (Relative)	**Power** Application	**Energy** Application
Pumped Storage	High Capacity, Low Cost	Special Site Requirement		●
CAES	High Capacity, Low Cost	Special Site Requirement, Need Gas Fuel		●
Flow Batteries: PSB VRB ZnBr	High Capacity, Independent Power and Energy Ratings	Low Energy Density	◐	●
Metal-Air	Very High Energy Density	Electric Charging is Difficult		●
NaS	High Power & Energy Densities, High Efficiency	Production Cost, Safety Concerns (addressed in design)	●	●
Li-ion	High Power & Energy Densities, High Efficiency	High Production Cost, Requires Special Charging Circuit	●	○
Ni-Cd	High Power & Energy Densities, Efficiency		●	◐
Other Advanced Batteries	High Power & Energy Densities, High Efficiency	High Production Cost	●	○
Lead-Acid	Low Capital Cost	Limited Cycle Life when Deeply Discharged	●	○
Flywheels	High Power	Low Energy density	●	○
SMES, DSMES	High Power	Low Energy Density, High Production Cost	●	
E.C. Capacitors	Long Cycle Life, High Efficiency	Low Energy Density	●	◐

EPRI Storage Handbook
Collaboration with the DOE/ESS Program

1. Introduction
   – Purpose
   – Electricity Storage Background and Experience Overview
   – Scope, including T&D Applications and ES Systems Overview
   – Guidelines/Cautions for Applications of ESH
   – Plan for Updates and Expansions
2. National Perspective of ES Benefits (DOE Outline)
3. T&D Applications for Benefit/Cost Assessments
   – Description of Selected ES Applications, including Graphics and Matrix with Distinguishing Range of Duty Parameters plus Specific Parameters for Benefit/Cost Assessments
   – Bases for Selected Combined Applications
   – Representative ES Systems Match-up with Applications
4. Energy Storage Benefits and Benefit Quantification
   – Bridge Discussion from National Benefits (Chapter 2)
   – Bases for ES Benefits per Application for T and/or D Utilities
   – Methodology and Input Parameters for Benefit Quantification, including Generic Examples
   – Methodology of Delineating Benefits for Combined Applications
5. Common Financial Parameters and Cost Elements
   – Cost Methodology and Groundrules
   – PCS Functionality and Cost per Application
   – BOP and Other Common Cost per Application

6-15. Individual ES Systems, namely PbA, NiCd, NAS, ZnBr, VRB, Regenesys, SMES, FW, UC, CAES
   – Description, Status, Applications, Benefits/Costs Assessment, References

- Other More Advanced ES – On Hold

Energy Storage R&D

- Small but active DOE program
- Industry Association
- Technology is emerging with some applications economical today
- The outlook for energy storage is bright

Reference Materials

- DOE/ESS Publications List
- Web sites

DOE ESS Program Publications List

SAND Report #	Title	Author(s)	Date	Document Location
SAND93-1754	Specific Systems Studies of Battery Energy for Electric Utilities	A. A. Akhil L. Lachenmeyer S.J. Jabbour N. H. Clark	Aug 93	http://infoserve.sandia.gov/sand_doc/1993/931754.pdf
SAND93-3900	Battery Energy Storage: A Preliminary Assessment of National Benefits (The Gateway Benefits Study). Sandia National Laboratories	A. A. Akhil, et al.	Dec 93	http://infoserve.sandia.gov/sand_doc/1993/933900.pdf
SAND94-2605	Battery Energy Storage for Utility Applications: Phase I – Opportunities Analysis. Sandia National Laboratories	P. C. Butler	Feb 94	http://infoserve.sandia.gov/sand_doc/1994/942605.pdf
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	"Sodium Beta Batteries," Handbook of Batteries, Chapter 12, McGraw Hill	J. W. Braithwaite W. L. Auxer	Jan 95	
SAND95-1545C	Assessment of Utility Side Cost Savings from Battery Energy Storage. Sandia National Laboratories. Proceedings of the 1996 IEEE Power Engineering Society Winter Meeting, Baltimore, MD	R. G. Jungst, M. D. Anderson, and J. T. Alt	Jan 96	http://infoserve.sandia.gov/sand_doc/1995/951545c.pdf

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	Energy Storage Solutions for Premium Power, in IEEE Aerospace and Electronics Systems, vol. 11, pp. 41-44	G. P. Corey	Jun 96	
	Lead-Acid Batteries in Systems to Improve Power Quality, Fifth European Lead Battery Conference, Barcelona, Spain	P. C. Butler P. Taylor W. Nerbun	Oct 96	
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SAND96-2900	Photovoltaic Battery & Charge Controller Market and Applications Survey	R. L Hammond J. F. Turpin G. P. Corey T. D. Hund S.R. Harrington	Dec 96	http://infoserve.sandia.gov/sand_doc/1996/962900.pdf
	DOE's Battery Storage Program, in Power Quality Assurance Magazine, Vol. 8, No. 1, p. 16	G. P. Corey G. A. Buckingham	Jan 97	
SAND97-0443	Cost Analysis of Energy Storage Systems for Electric Utility Applications	Akhil R. K. Sen S. Swaminathan	Feb 97	http://infoserve.sandia.gov/sand_doc/1997/970443.pdf

	Battery storage all but eliminates diesel generator, in Electrical World	M. Demarest P. Taylor D. Achenbach A. A. Akhil	Jun 97	
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	T&D in Alaska: Like an undeveloped nation, in Electrical World	P. Taylor, M. Demarest, and P. C. Butler	Aug 97	
SAND97-1136	Energy Storage Systems Program Report 1996	P. C. Butler	Aug 97	http://infoserve.sandia.gov/sand_doc/1997/971136.pdf
SAND97-2334C	Battery evaluation methods and results for staionary applications	Butler; Paul Charles; Crow; James Terry; Taylor, Paula A. Energetics, Inc., Columbia, MD.	Sep 97	http://infoserve.sandia.gov/sand_doc/1997/972334c.pdf
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SAND98-0591	Renewable Generation & Storage Project Industry & Laboratory Recommendations	N.C. Clark P. Butler C.P. Cameron	Mar 98	http://infoserve.sandia.gov/sand_doc/1998/980591.pdf

SAND98-1513	Review of Power Quality Applications of Energy Storage Systems	S. Swaminathan and R. K. Sen	Jul 98	http://infoserve.sandia.gov/sand_doc/1998/981513.pdf
SAND98-1905	Battery Energy Storage Systems Life Cycle Costs Case Studies	S. Swaminathan, N. F. Miller, and R. K. Sen	Aug 98	http://infoserve.sandia.gov/sand_doc/1998/981905.pdf
SAND98-1733	Energy Storage Systems Program Report for FY97	P. C. Butler	Aug 98	http://infoserve.sandia.gov/sand_doc/1998/981733.pdf
SAND98-1904	Analysis of the Value of Battery Energy Storage with Wind & Photovoltaic Generation to the Sacramento Municipal Utility District	H. Zaininger	Aug 98	http://infoserve.sandia.gov/sand_doc/1998/981904.pdf
SAND97-1276	Final Report on the Development of a 250-kW Modular, Factory-Assembled Battery Energy Storage System	G. P. Corey W. Nerbun D. Porter	Aug 98	http://infoserve.sandia.gov/sand_doc/1997/971276.pdf
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SAND99-0935	System and Battery Charge Control for PV-Powered AC Lighting Systems	G. Kern	Apr 99	http://infoserve.sandia.gov/sand_doc/1999/990935.pdf
SAND99-0936	Solar-Powered Systems for Environmental Remediation	C. Miralles, B. Jensen, A. Flack, B. Yelin, J. Cromwell, R. Lopez, and S. Berge	Apr 99	http://infoserve.sandia.gov/sand_doc/1999/990936.pdf
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- DOE Home Page
  - http://www.energy.gov/engine/content.do
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- EESAT Conference
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III. Cont.
Economic Analysis of Energy Storage

Instructor – John Boyes, Sandia National Lab

DOE Energy Storage Systems Program is conducting economic analysis of the costs and benefits of electric energy storage

- Life Cycle System Costs by Susan Schoenung and William Hassenzahl
- Benefits and Market Analysis by Joe Iannucci and Jim Eyer
- Compare Capital Costs with Benefits – work in progress

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Life Cycle Cost Analysis Application Categories

Application Category	Discharge Power Range	Discharge Time Range	Stored Energy Range	Representative Applications
Bulk Energy Storage	10-1000 MW	1-8 hrs	10-8000 MWh	Load leveling, spinning reserve
Distributed Storage	100-2000 kW	0.5-4 hrs	50-8000 kWh	Peak shaving, transmission deferral
Power Quality	0.1-2 MW	1-30 sec	0.1-60 MJ (0.028-16.67 kWh)	End-use power quality and reliability

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PCS* Costs for Long-Term Operation

Technology	250 kW		1 MW		5 MW		20 MW	
	1st unit	10th unit	1st unit	10th unit	1st unit	10th unit	1st unit	10th unit
Flywheel	500	225	300	175	200	150	150	125
Battery	500	225	300	175	200	150	150	125
SMES	550	250	350	200	250	175	200	150

Note: Power rating is based on continuous operation.
Note: All costs are in $/kW.
*PCS – Power Conditioning System

PCS Costs for Short-Term Operation 0 to 30 seconds

Technology	250 kW		1 MW		5 MW		20 MW	
	1st unit	10th unit	1st unit	10th unit	1st unit	10th unit	1st unit	10th unit
Flywheel	350	150	200	175	140	100	100	90
Battery	350	150	200	175	140	100	100	90
SMES	400	175	250	200	190	125	150	115

Note: All costs are in $/kW.

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Capital Costs

Technology	Energy-Related Cost ($/kWh)	Power–Related Cost ($/kW)	Balance of Plant (Bulk Storage) ($/kWh)
Lead-acid Batteries (Flooded Cell)	150	125	150
Lead-acid Batteries (VRLA)	200	125	150
Ni/Cd	600	125	150
Regenesys®	100	275	50
High Temp Na/S	250	150	50
CAES	3	425	50
Pumped Hydro	10	1000	4
Pumped Hydro Variable Speed	10	1050	4

Other Cost Parameters

Technology	Efficiency (AC to AC)	Replacement Cost ($/kWh)	Replacement frequency (yr)	Fixed O&M ($/kW-yr)
Lead-acid Batteries (Flooded Cell)	0.75	150	6	15
Lead-acid Batteries (VRLA)	0.75	200	5	5
Ni/Cd	0.65	600	10	5
Regenesys®	0.65	$150/kW	10	15
High Temp Na/S	0.7	230	10	20
(CAES)	0.73	0	None	2.5
Pumped Hydro	0.75	0	None	2.5
Pumped Hydro Variable Speed	0.78	0	None	2.5

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Levelized Annual Cost Definition

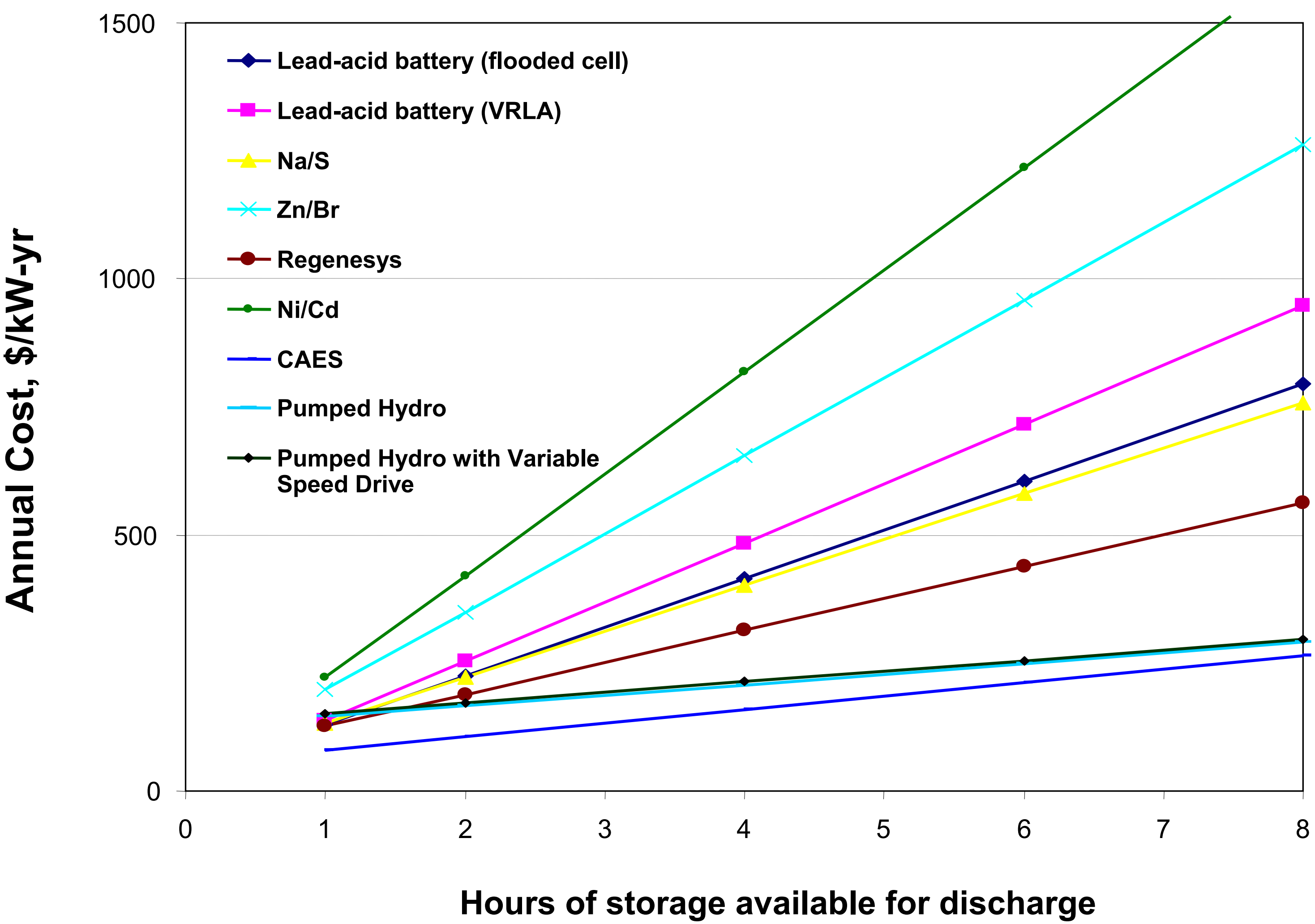
(LAC) ($/kW-yr) =
financial carrying charge for capital equipment
+ levelized fixed O&M costs
+ levelized annual costs for replacement parts
+ levelized variable costs for energy and O&M

Economic Parameters for Life-Cycle Cost Analysis

Parameter	Value
General inflation rate	2.5%
Discount rate	8.5%
Levelization period	20 years
Carrying charge rate	12%
Fuel cost, natural gas	5 $/MBTU
Fuel cost escalation rate	0%
Electricity cost	5 ¢/kWh
Electricity cost escalation rate	0%
O&M cost escalation rate	0%

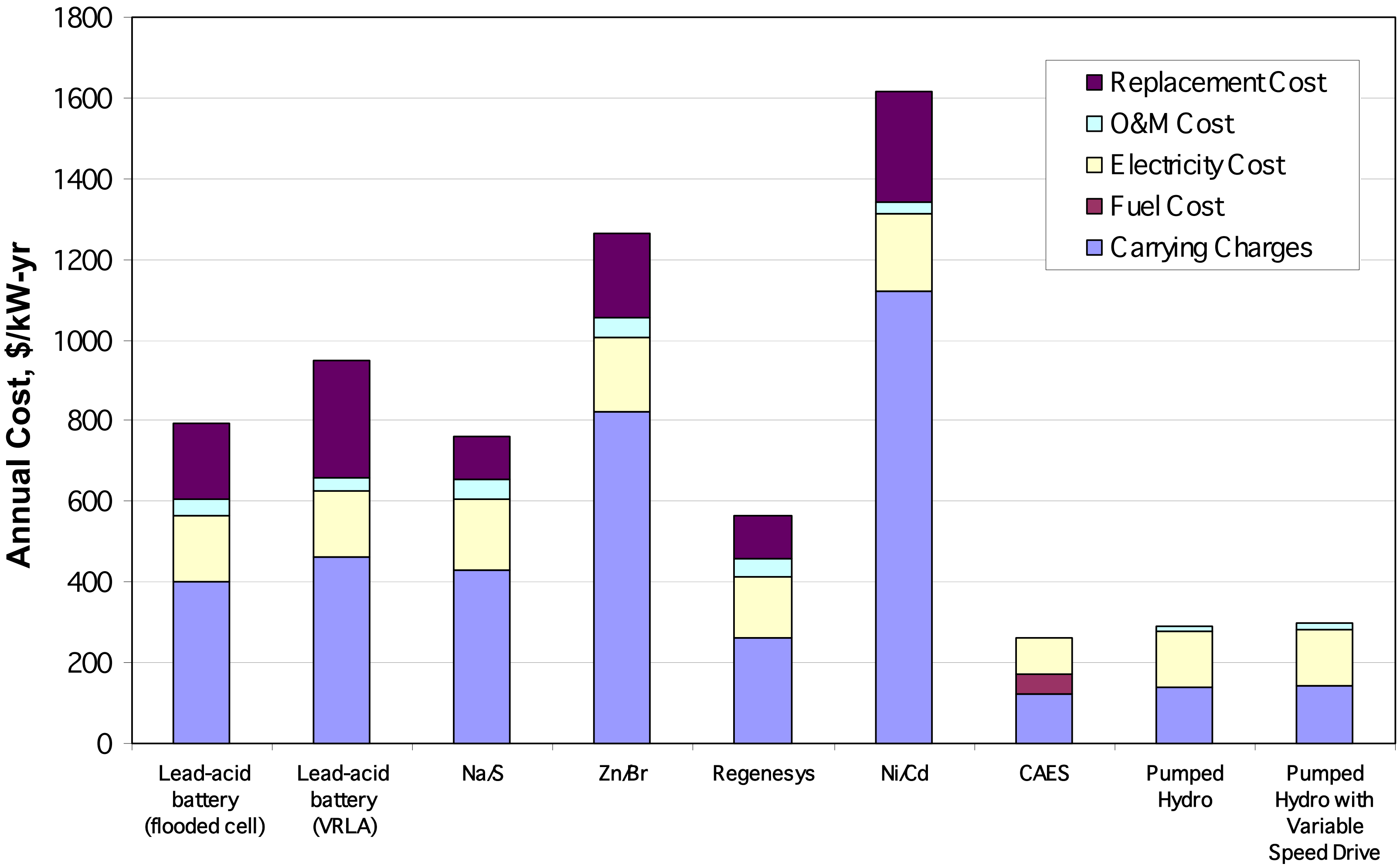
Levelized Annual Cost

Bulk Energy Storage Technologies (10-1000 MW)



Components of Annual Cost

Bulk Storage Technologies (8 hr discharge)



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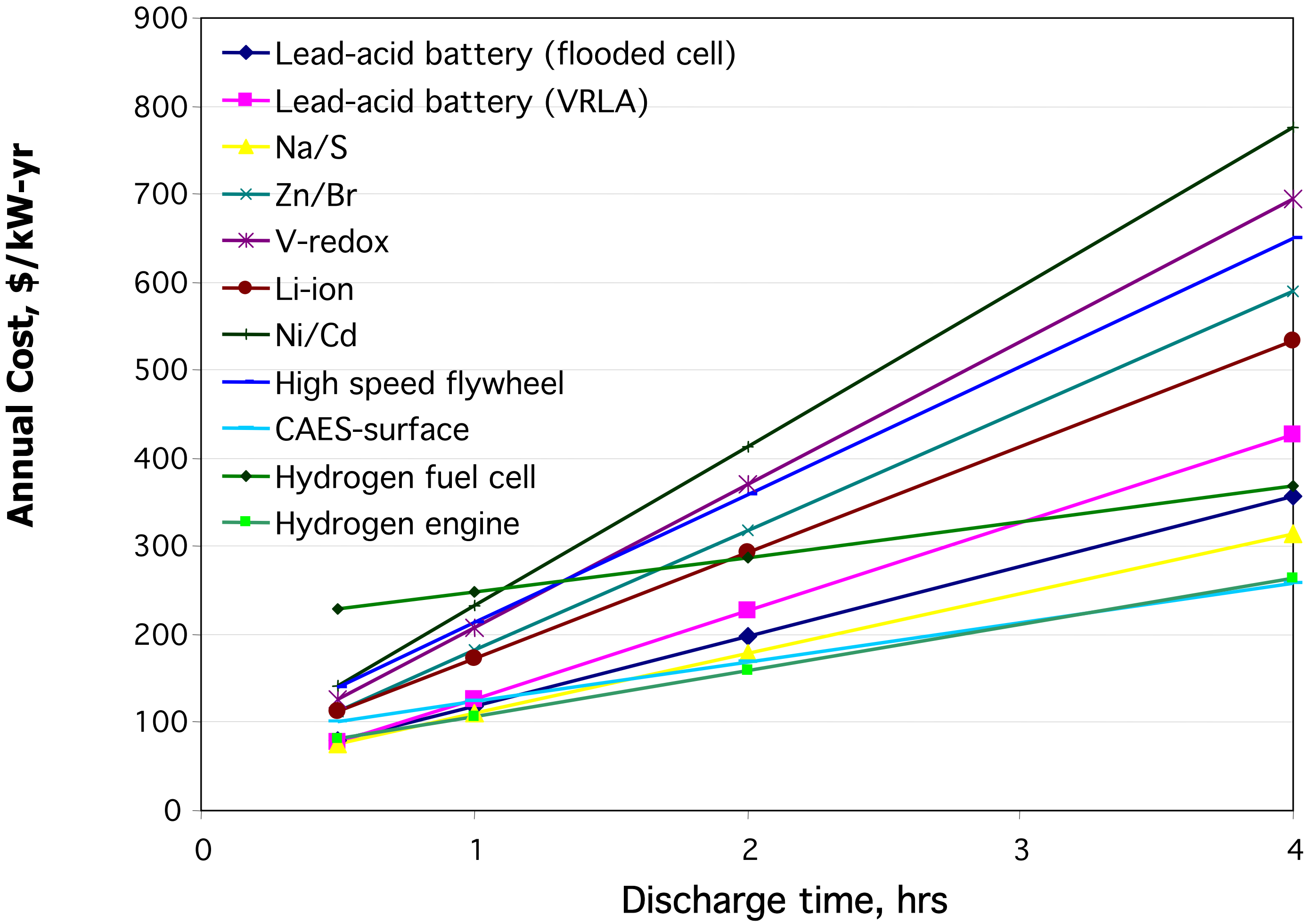
Levelized Annual Cost
Distributed Storage Systems (100 kW-2 MW)



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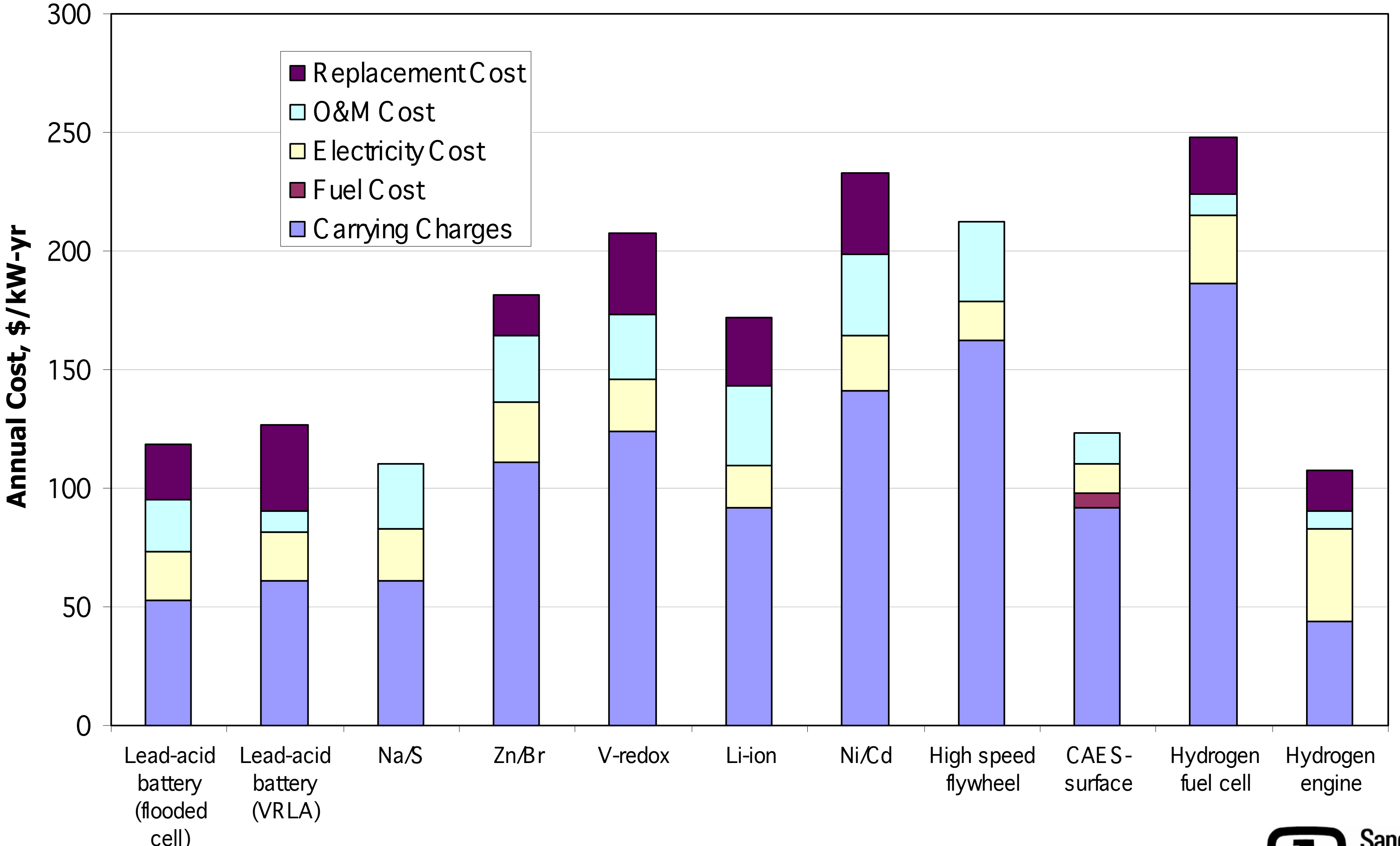
Components of Annual Cost
Distributed Storage Technologies (1 hour discharge)



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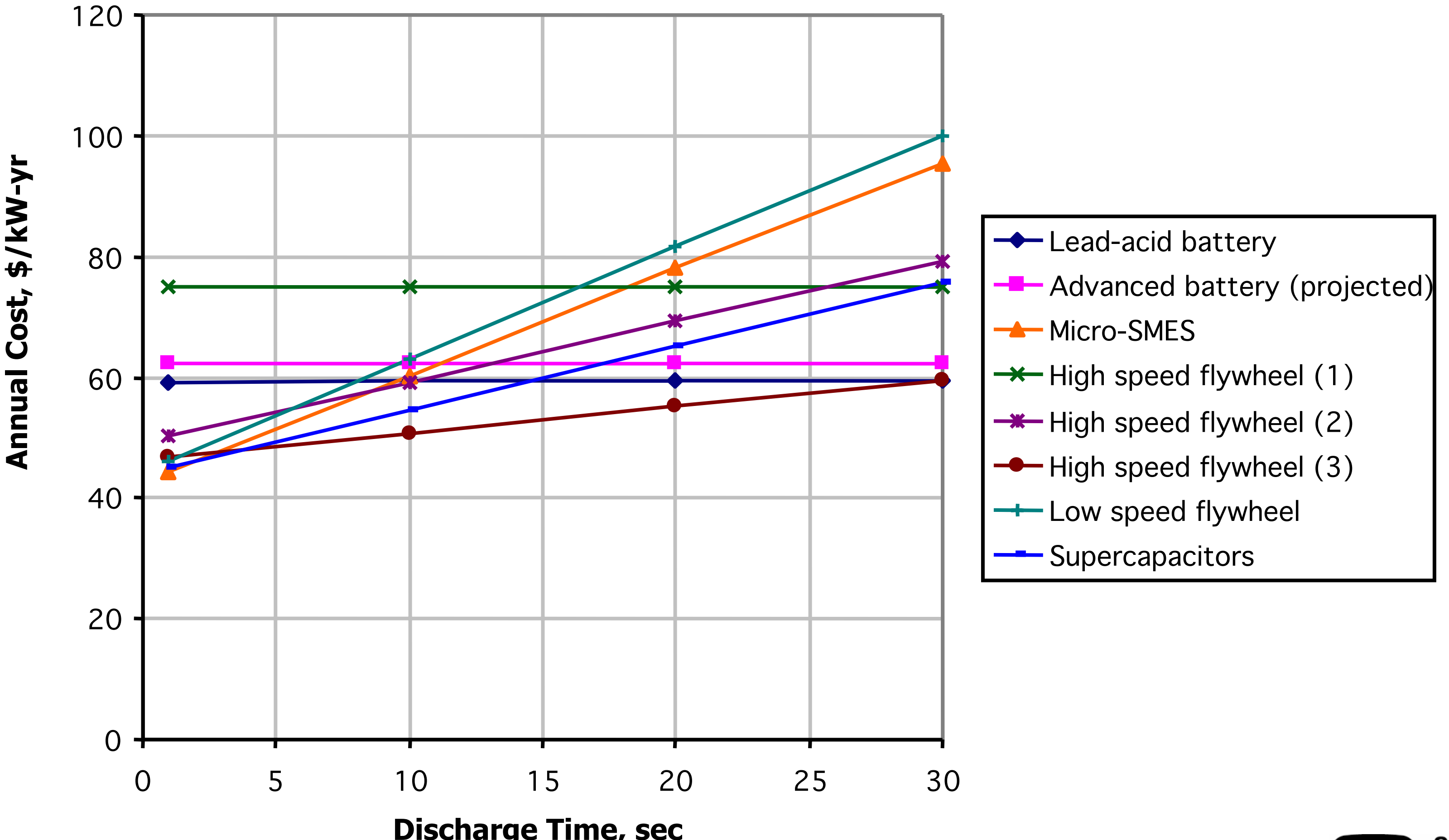
Levelized Annual Cost

Power Quality Technologies (100 kW - 2 MW)



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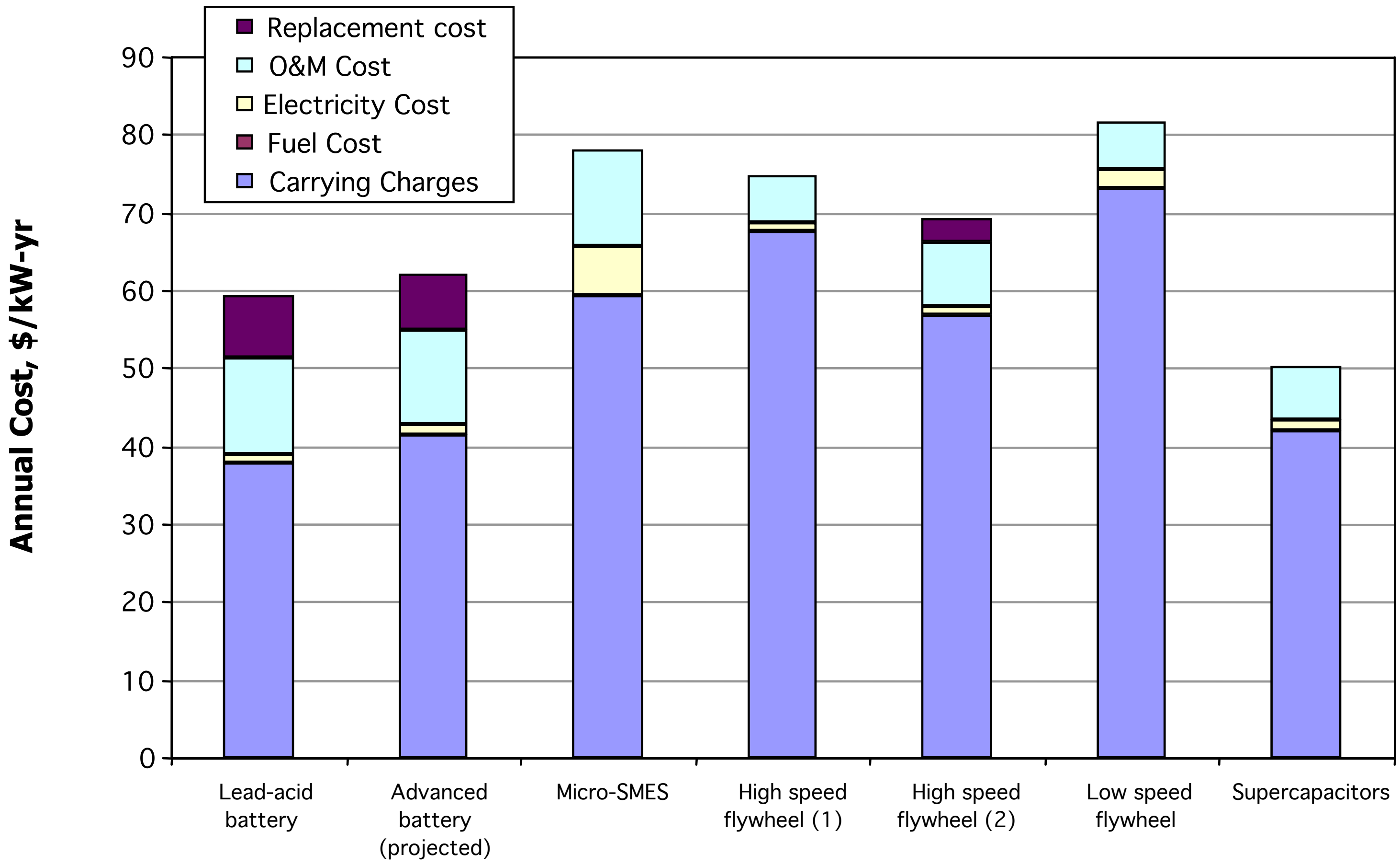
Components of Annual Cost

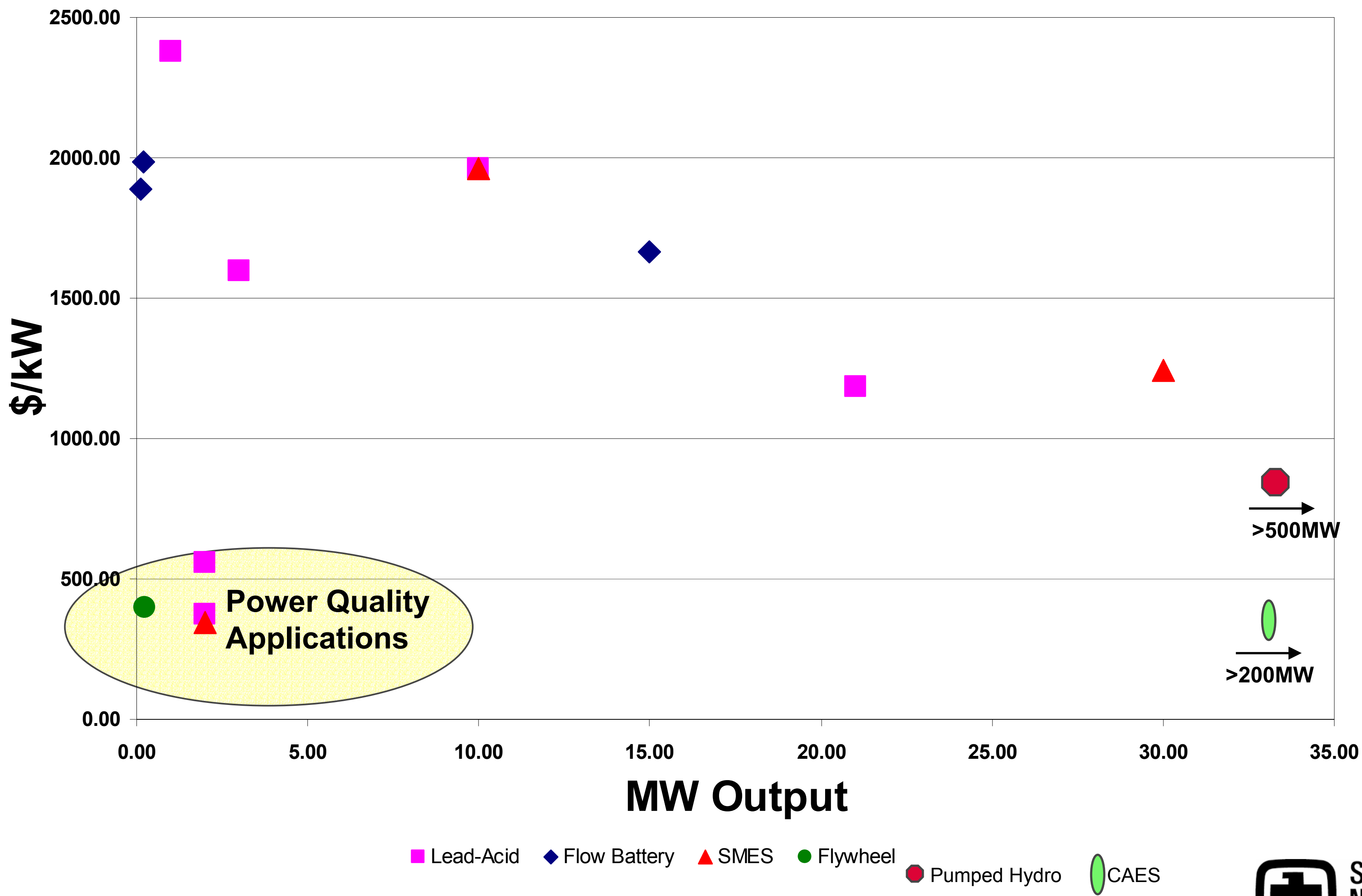
Power Quality Technologies (20 sec discharge)



Summary of System Costs
Year 2000 US $

System Identification	System power rating MW	Total Cost $k/kW	System Storage MWh	Total Cost $/kWh	Comments
Puerto Rico BESS	21.00	1184.25	14.10	1763.78	1992
Chino	10.00	1961	40.00	490	1988
Vernon	3.00	1595	4.50	1063	1995
PQ2000	2.00	557	0.006	200629	Prototype
Purewave	2.00	375	0.017	45000	Early Production
Metlakatla	1.00	2376	1.40	1697	Remote
Powercell	0.10	1890	0.10	1890	Early Production
ZBB	0.20	1984	0.40	992	Estimate
Regenesys	15.00	1667	120.00	208	Estimate
ASC DSMES	2.00	343	0.0007	1030000	Early Production
SMES PREPA					
10MW	10.00	1963	0.10	188477	Estimate
30MW	30.00	1245	0.31	119517	Estimate
50MW	50.00	1071	0.52	102831	Estimate
60MW	60.00	1027	0.63	98611	Estimate
70MW	70.00	931	0.73	89336	Estimate
CAT UPS Flywheel	0.25	400	0.0011	92308	Early Production

System Costs Year 2000 US $/kW



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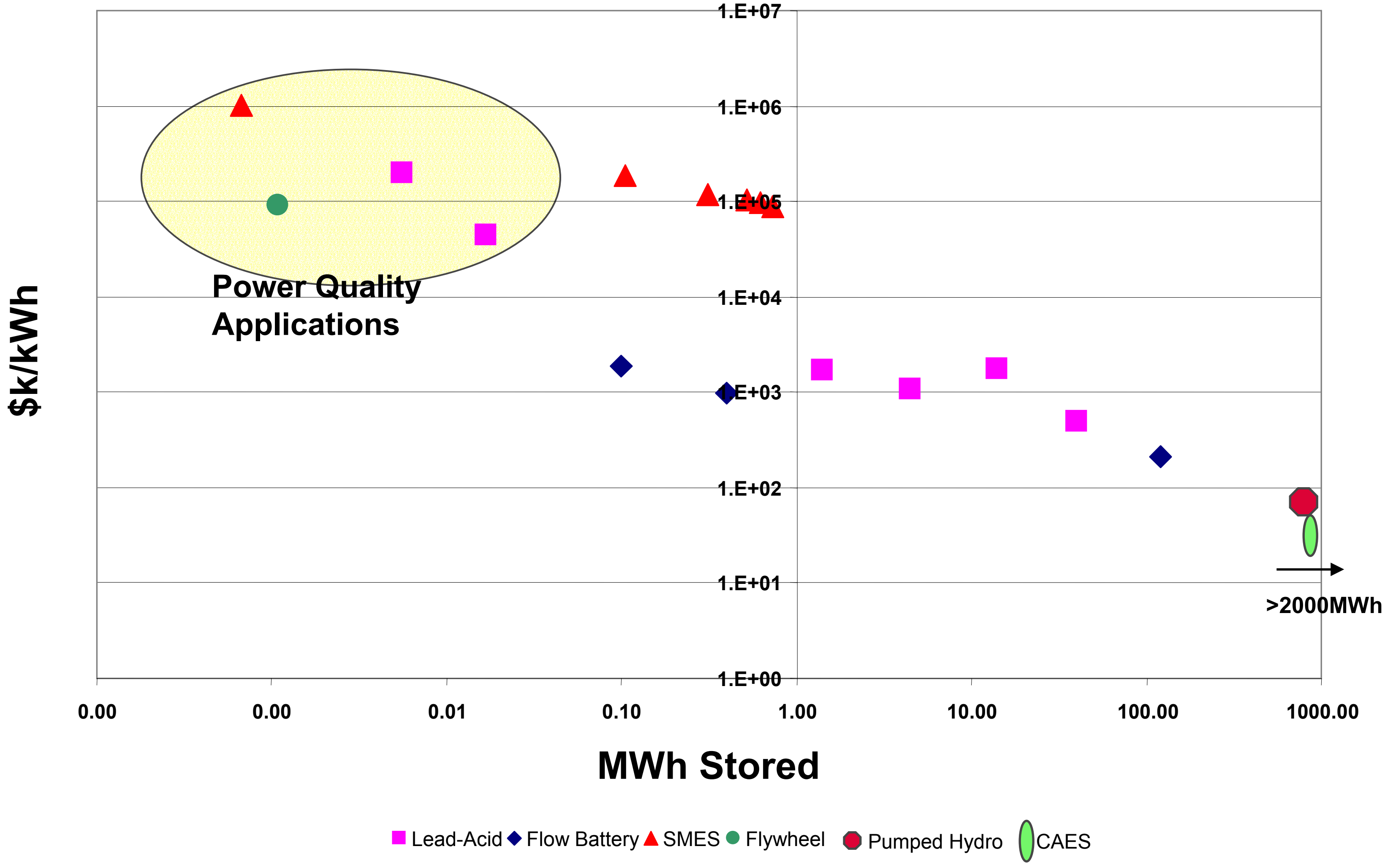
System Costs Year 2000 US $k/kWh



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General Applications Comparisons - Plant Cost Estimate

Energy Storage Technology	Plant Size	Energy Storage	Estimated Plant Cost ($/kW)	Technology Maturity	Expected Cost Reduction Over 10 Year Period
CAES	350 MW	10 hrs	500	Mature	None
CAES Hybrid	20 MW	4 hrs	700	Demonstartion	20%
Pumped Hydor	1000 MW	4 hrs	$1,000	Mature	None
Lead Acid Battery	20 MW	2 hrs	$1,200	Mature	5%
Regenesys	12 MW	10 hrs	$2,000	Demonstartion	25%
NAS Battery	6MW	8 hrs	$2,000	Demonstartrion	20%
VRB	500 kW	10 hrs	$3,500	Trial	20%
Ucap	100kW	10 sec	$800	Trial	30%
UCAP	3 MW	6 sec	$600	Concept	30%
Flywheel	1kW	4 hrs	$8,000	Demonstartion	20%
Flywheel	300 kW	15 sec	$330	Mature	5%
Flywheel	5 MW	10 sec	$400	Concept	25%

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Comparing Costs and Benefits

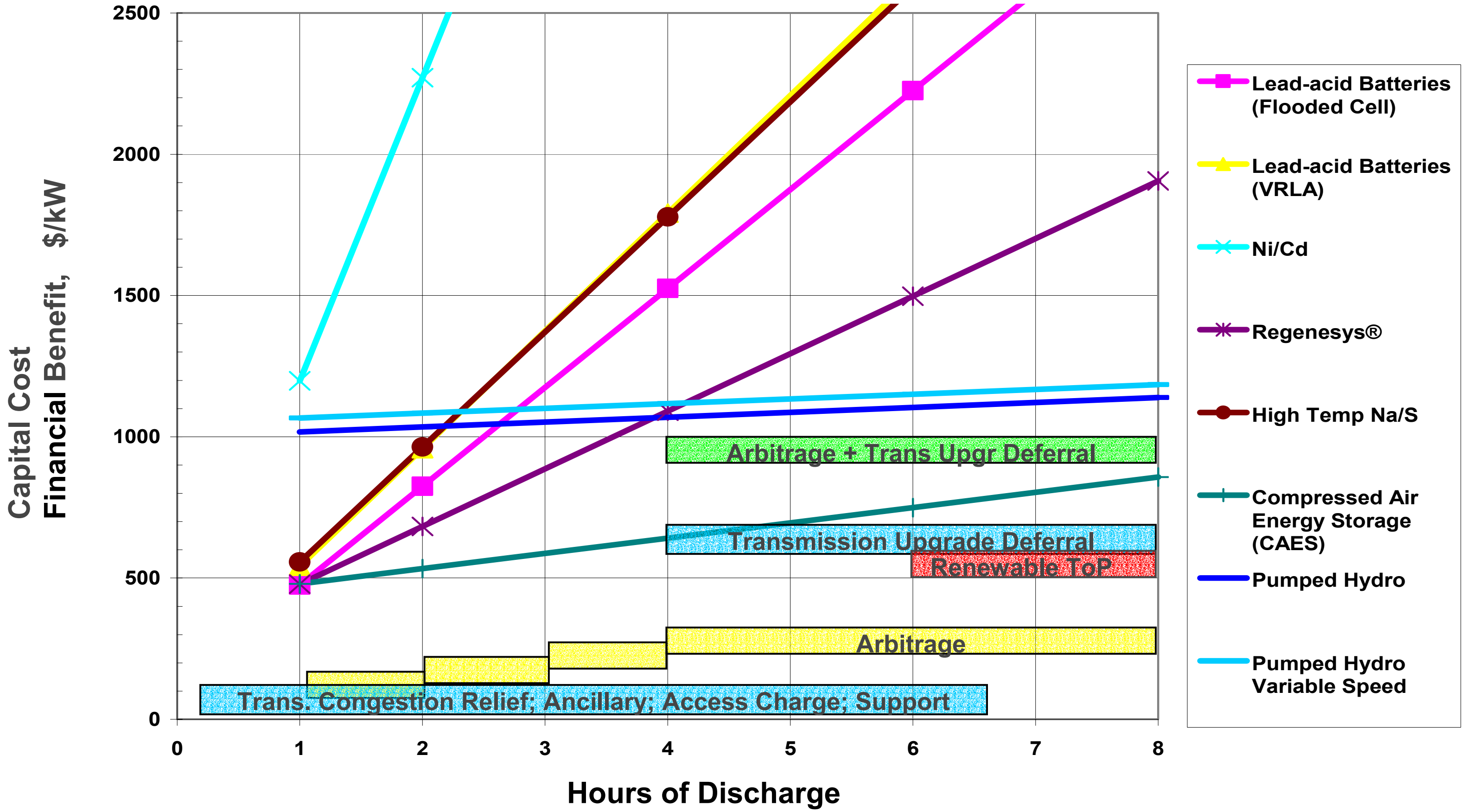
- Life Cycle cost analysis calculated levelized annual cost based on 20 year lifetime
- Benefits and Market analysis calculated total economic benefit over 10 years

To combine the two studies

- Capital costs only
- Replacement costs not included
- O&M and Charging costs included in Benefit calculation
- Benefits calculated for California Market

Capital Cost and Financial Benefit

Bulk Storage Power > 10MW, Time 1-8 Hours



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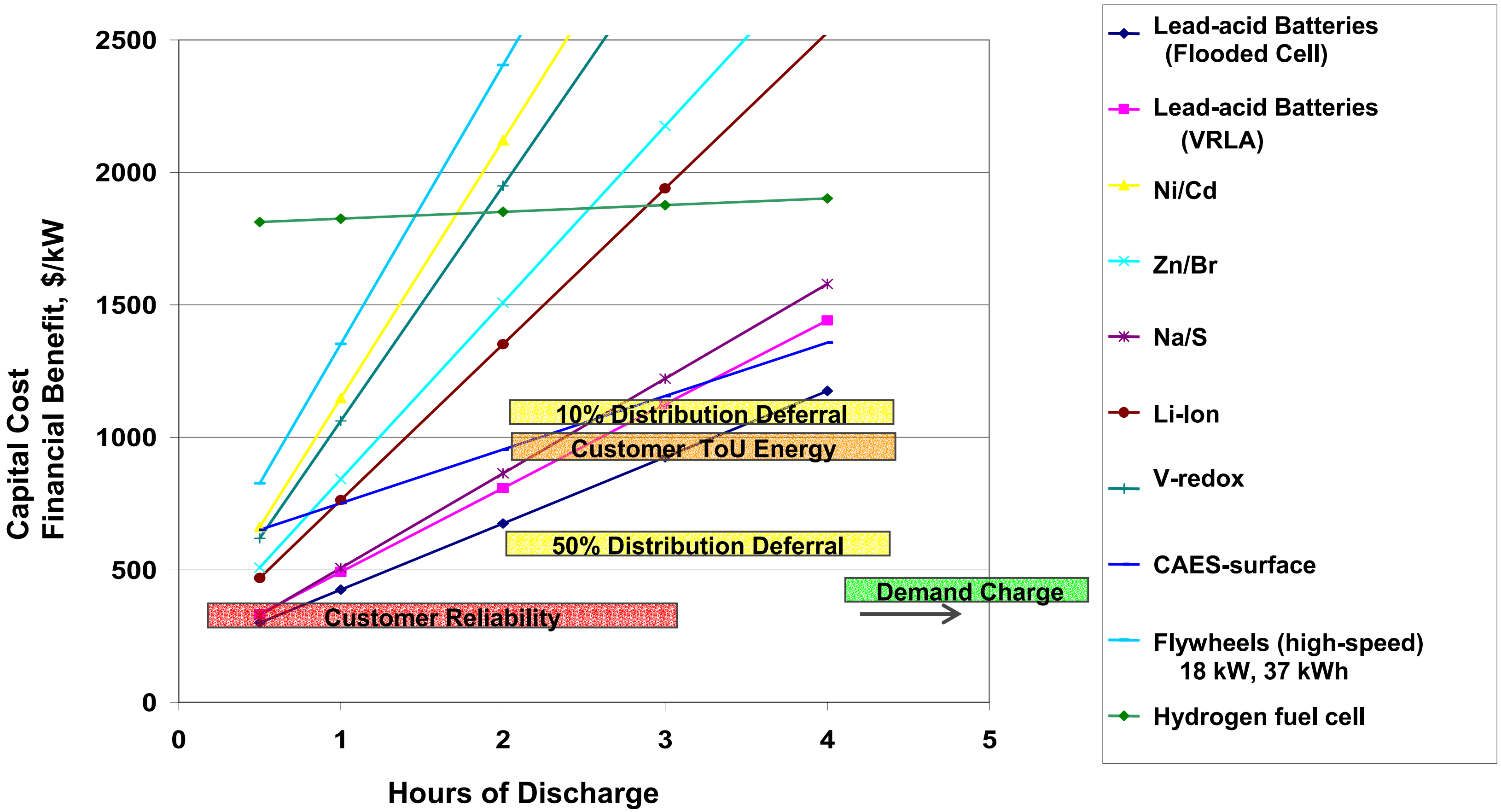
Capital Cost and Financial Benefit

Distributed Storage, 100kW – 2 MW, ½ - 4 Hours



Distribution Upgrade & Customer TOU Projects?

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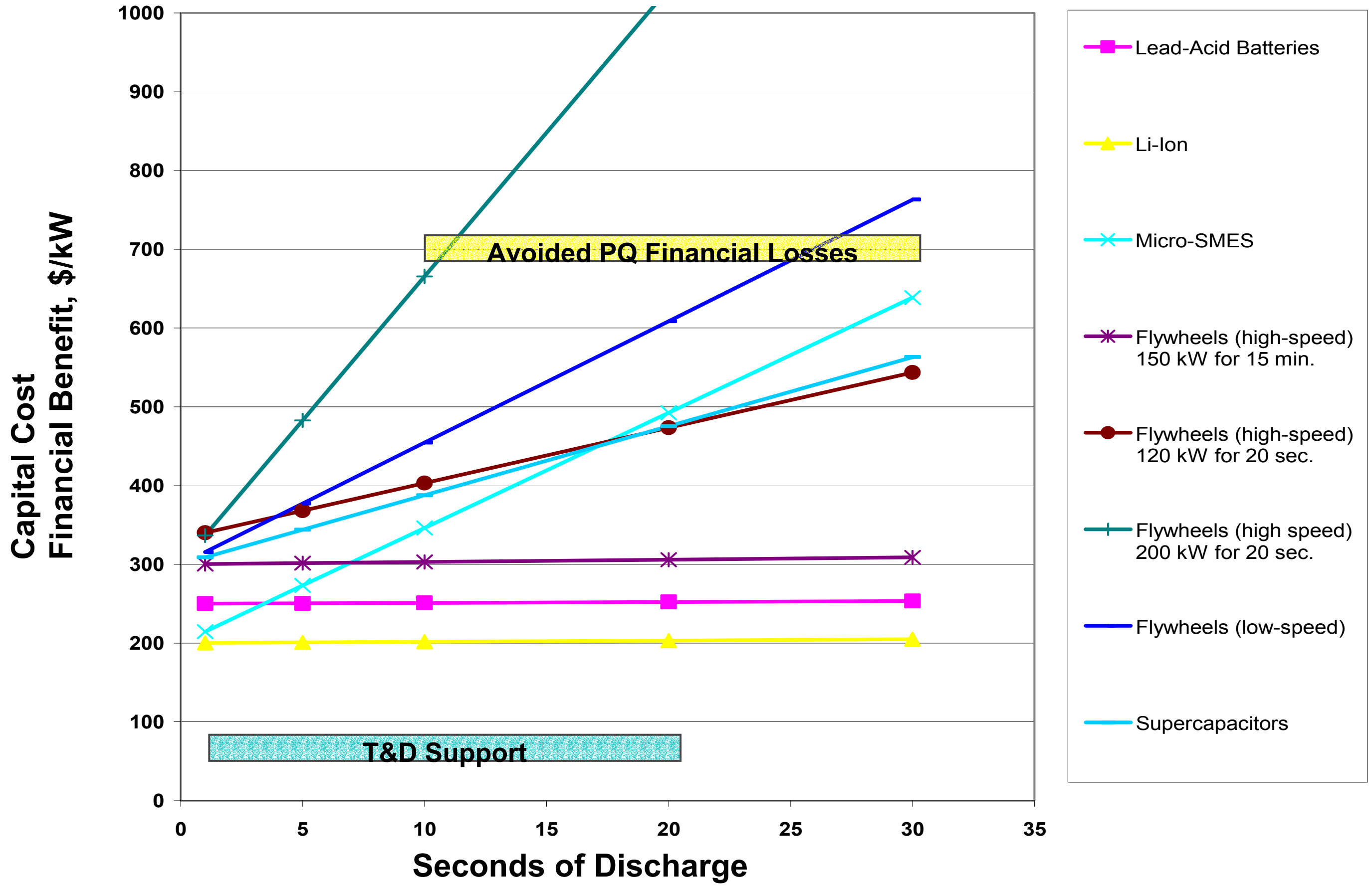
Capital Cost and Financial Benefit
Power Quality Applications



Conclusions

- A methodology has been developed to calculate the Life Cycle Cost of systems
- A methodology for calculating benefits and potential markets has been developed
- With current system costs, combining benefits shows potential markets today
- This work is exploring new ways is which storage can provide significant benefits in the near term
- Additional research is needed to fully understand the storage cost – benefit relationship

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