Overview of Energy Storage Cost Analysis

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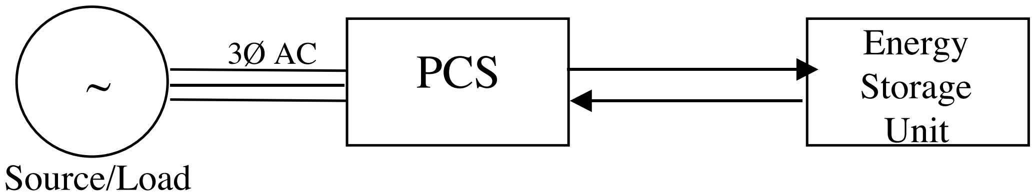
Outline of Presentation

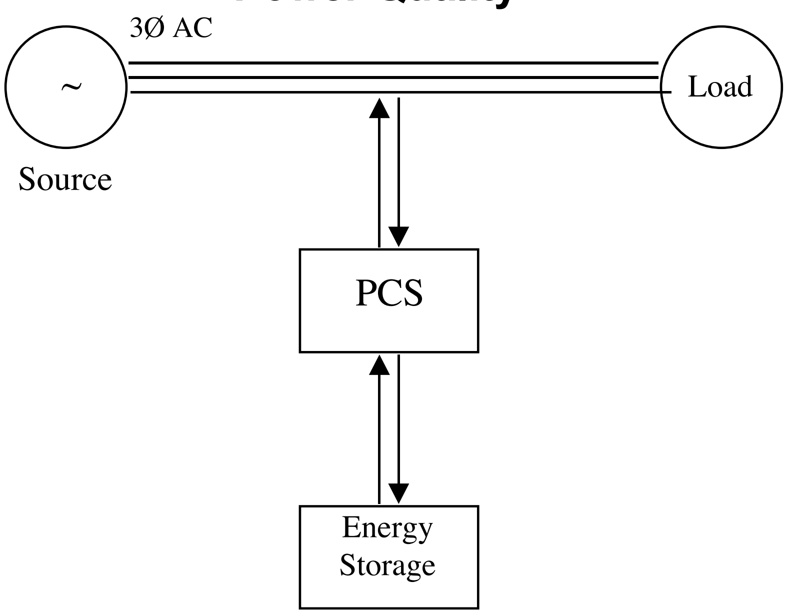
- Review of energy storage system configurations and components
- Capital cost analysis
- Life cycle cost analysis
- Present value analysis
- Some results
- Summary and conclusions

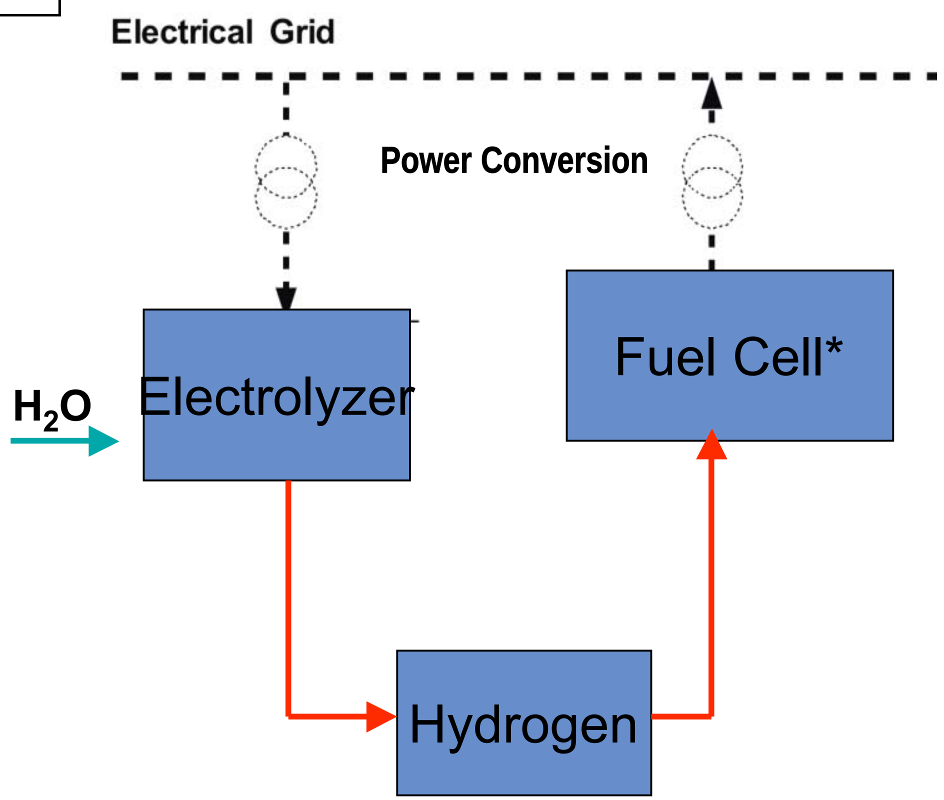
Energy Storage System Configurations and Components

Load Management



Power Quality





Energy Storage System Applications

- Bulk storage
- Distributed storage
- Power quality

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 generation	100 - 2000 kW	0.5 - 4 hrs	50 - 8000 kWh (0.05 - 8 MWh)	Peak shaving, transmission deferral
Power quality	100 - 2000 kW	1 - 30 sec	0.1 - 60 MJ (0.028-16.67 kWh)	End-use power quality and reliability

Energy Storage System Technologies

Bulk Energy Storage	Distributed Generation	Power Quality
Lead-acid batteries Na/S batteries Regenesys Zn/Br batteries Ni/Cd CAES Pumped hydro Lead-carbon asymmetric caps	Lead-acid batteries Na/S batteries Ni/Cd Li-ion batteries Zn/Br batteries V-redox batteries High-speed flywheels CAES-surface Lead-carbon asymmetric caps Hydrogen fuel cell Hydrogen engine	Lead-acid batteries Li-ion batteries High-speed flywheels Low-speed flywheels SMES Supercapacitors

Operational Use Profiles

Category/Definition	Hours of Storage	Use/Duty Cycle	Representative Application
Long-duration storage, frequent discharge	4 – 8*	1 cycle/day × 250 days/year	Load-levelling, source-following
Long-duration storage, infrequent discharge	4 – 8*	20 times/year	Capacity credit
Short-duration storage, frequent discharge	0.25 – 1**	4×15 minutes of cycling × 250 days/year = 1000 cycles/year	Frequency or area regulation
Short-duration storage, infrequent discharge	0.25 – 1**	20 times/year	Power quality, momentary carry-over

Costs

- Capital: up-front investment costs for storage unit, power electronics and balance-of-plant
- Replacement costs: storage system components
- Operating costs: energy, O&M

Capital Cost Calculation

$Cost_{total}(\$) = Cost_{pcs}(\$) + [Cost_{storage}(\$) + Cost_{Bop}(\$)]$

$E_{storage}(kWh) = Power(kW) \times time\ (hr)$

$Cost_{total}(\$) = [P(kW) \times Cost_{pcs}(\$/kW)] + [Cost_{storage+BOP}(\$/kWh) \times time\ (hr) \times Power(kW)]$

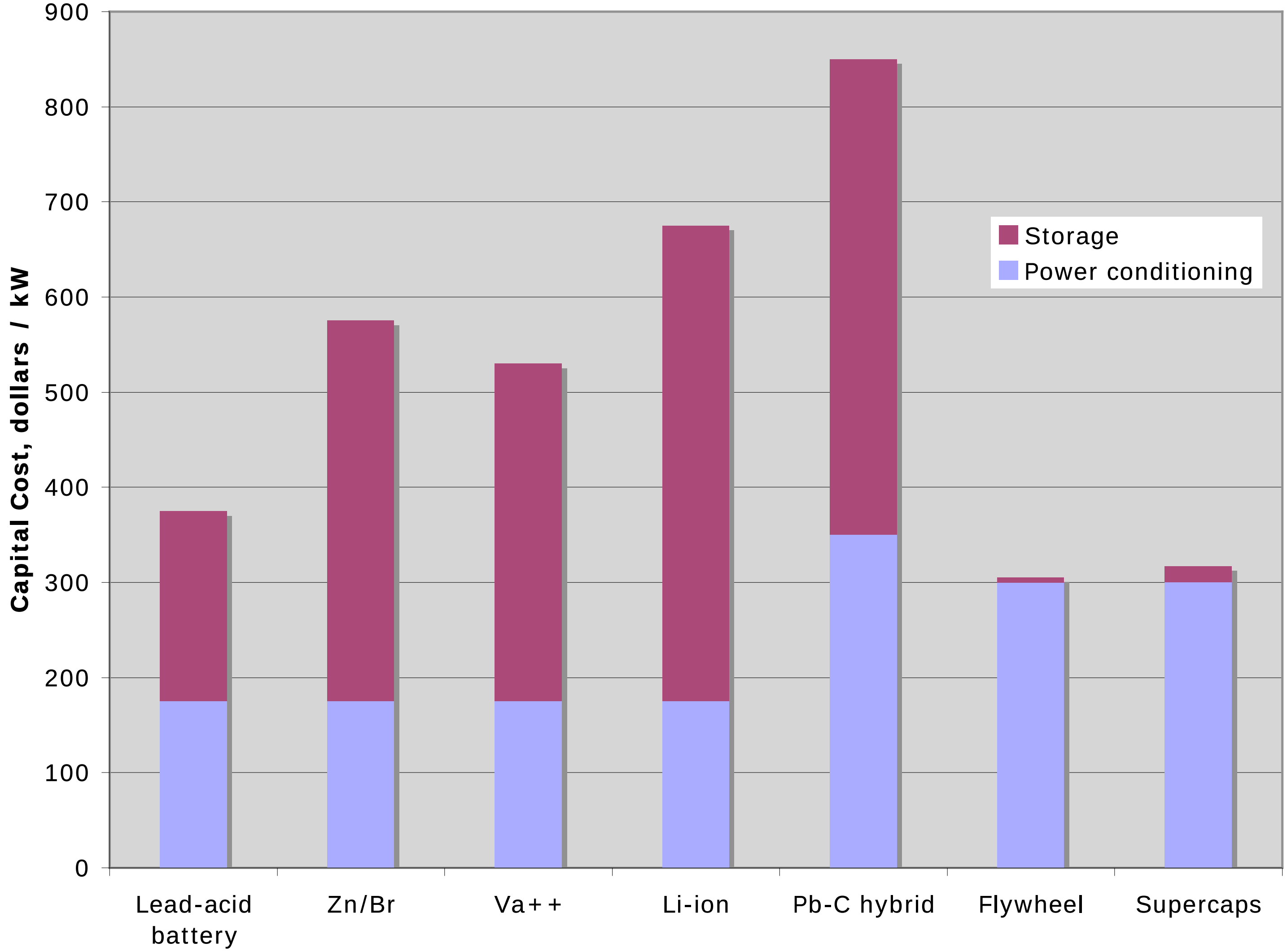
$Cost_{total}(\$/kW) = Cost_{pcs}(\$/kW) + Cost_{storage+BOP}(\$/kWh) \times time\ (hr)$

Message: The storage and power electronics are usually costed separately!

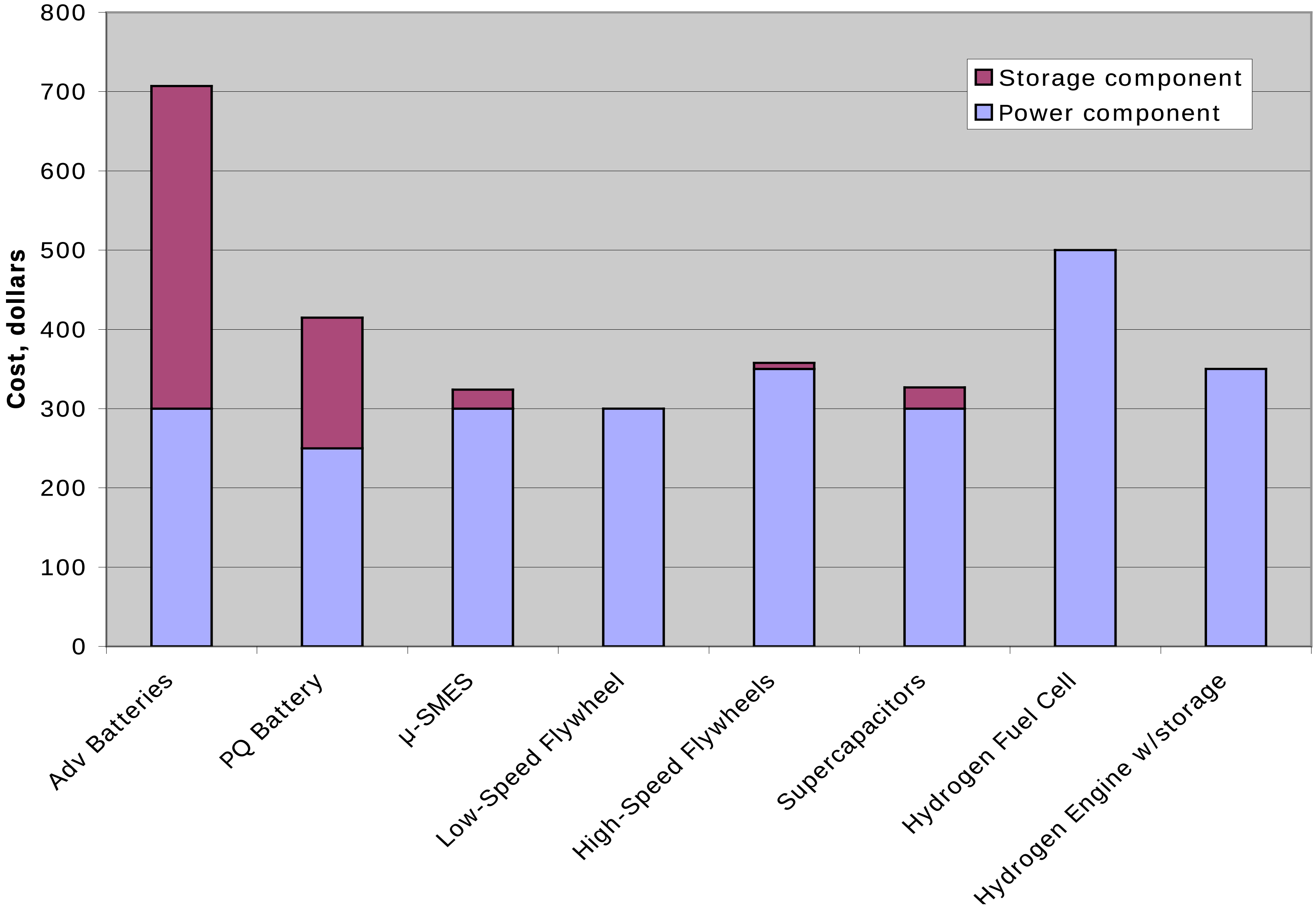
General Capital Cost Trends

- Storage range:
  - $250 - $1000/MWh
  - depends on technology
- Power conditioning system range:
  - $150 - $500/kW
  - Depends on usage, discharge & charge times
  - Depends on technology

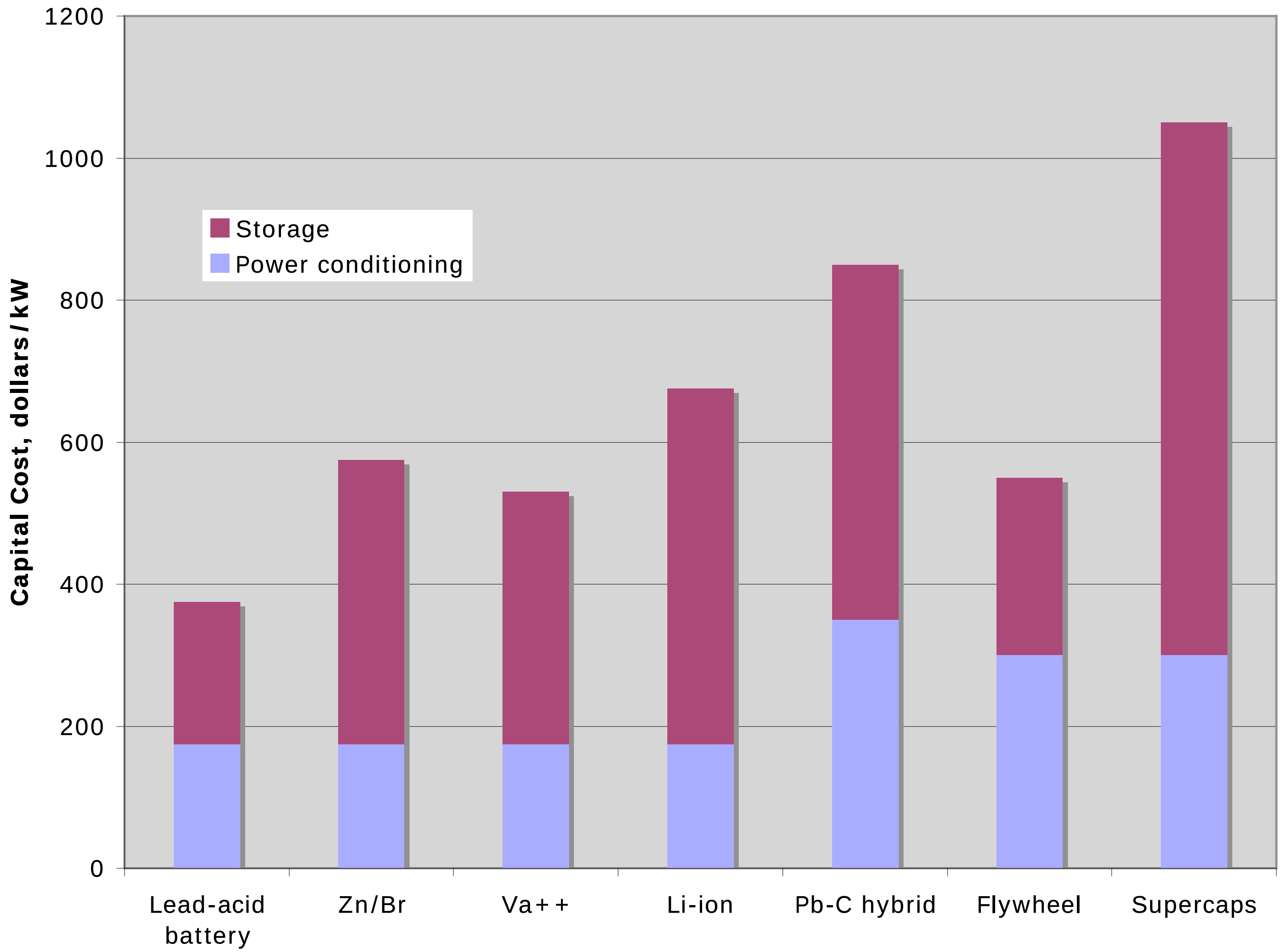
Examples for power quality (20 sec)



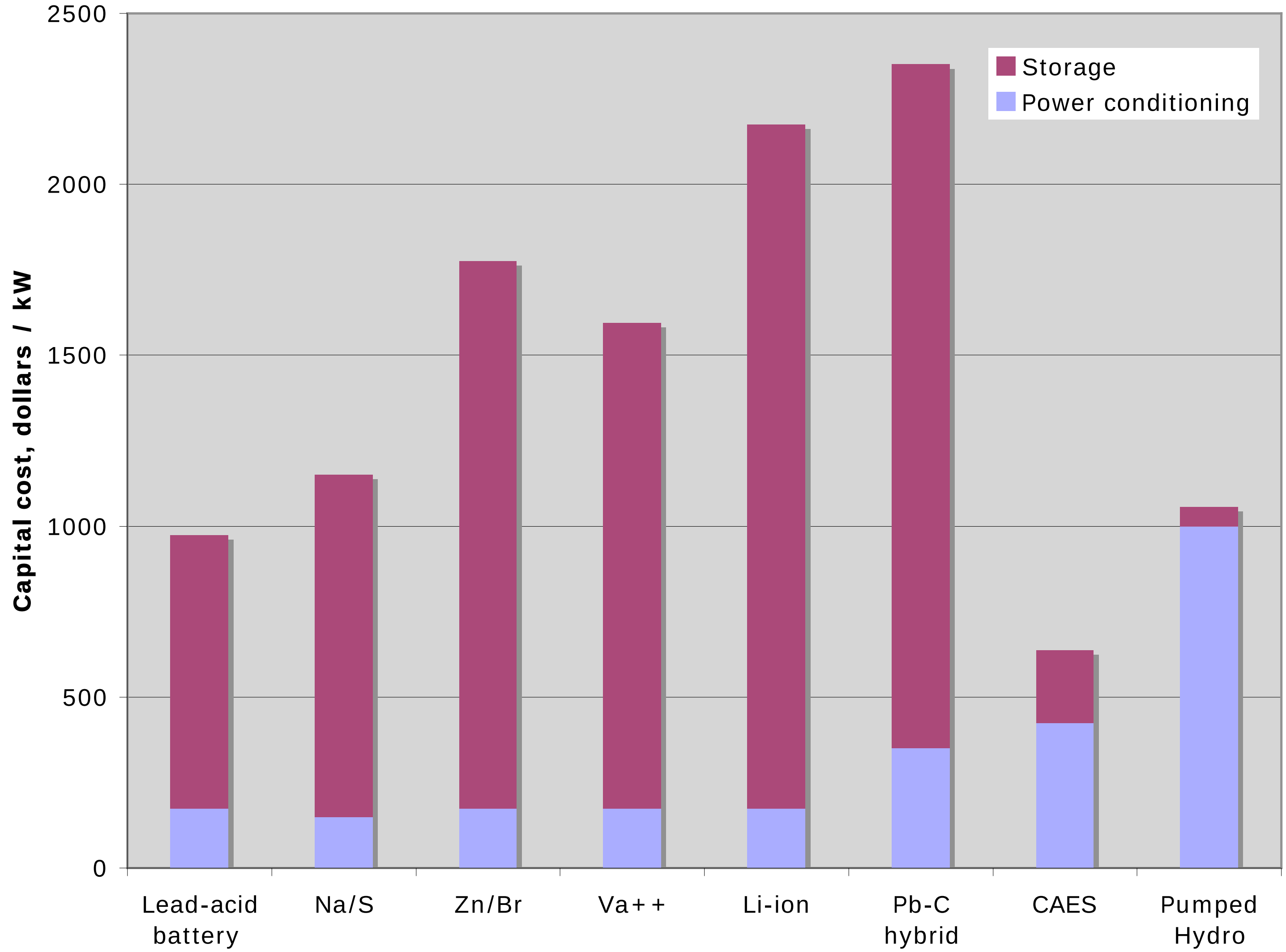
Examples for power quality (1 sec)



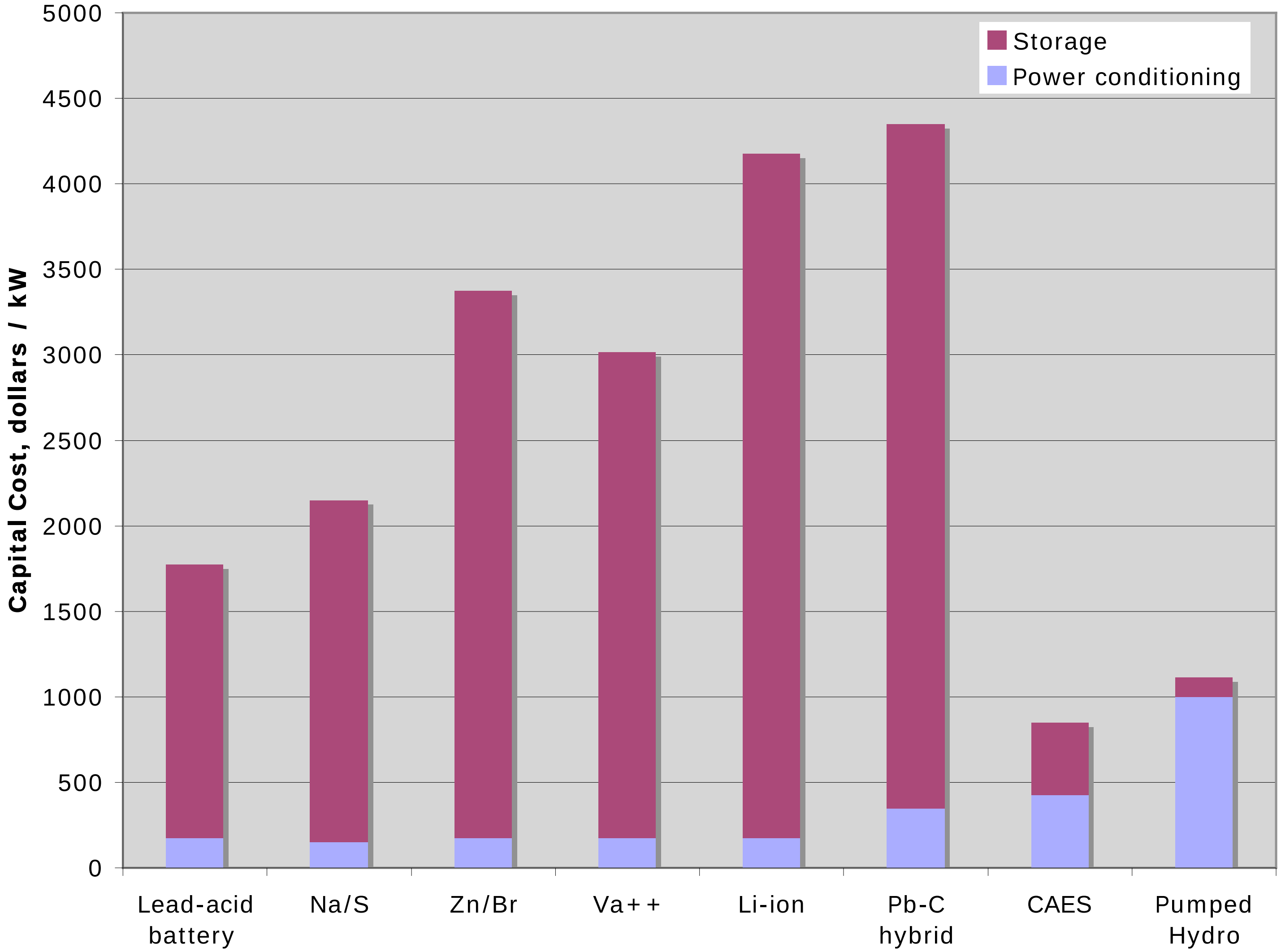
Example for voltage regulation (15 min)



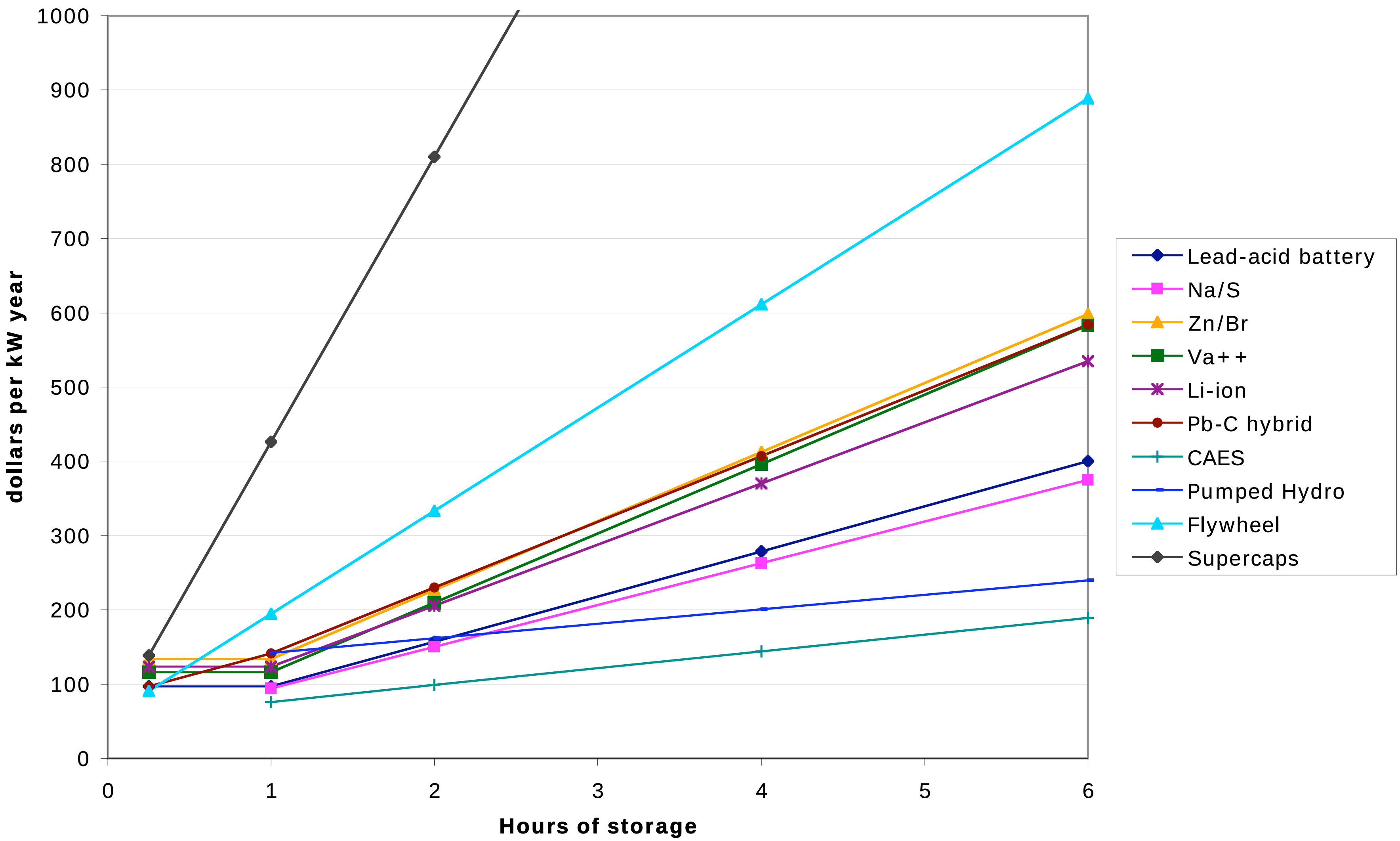
Example for distributed storage (4 hrs)



Example for bulk storage (8 hrs)



Costs increase with discharge time



Life-cycle Cost Analysis

Gives a better view of energy storage system cost, because it considers differences in

- System operating life (payment period)
- Efficiency
- Operating cycles: hours/day, days/week, cycles per year
- Parasitic losses
- Replacement costs

Annual Cost Calculation

Levelized annual cost ($/kw-yr)

= Cost of capital (carrying charge on initial purchase)

+ cost of fixed O&M

+ cost of variable O&M

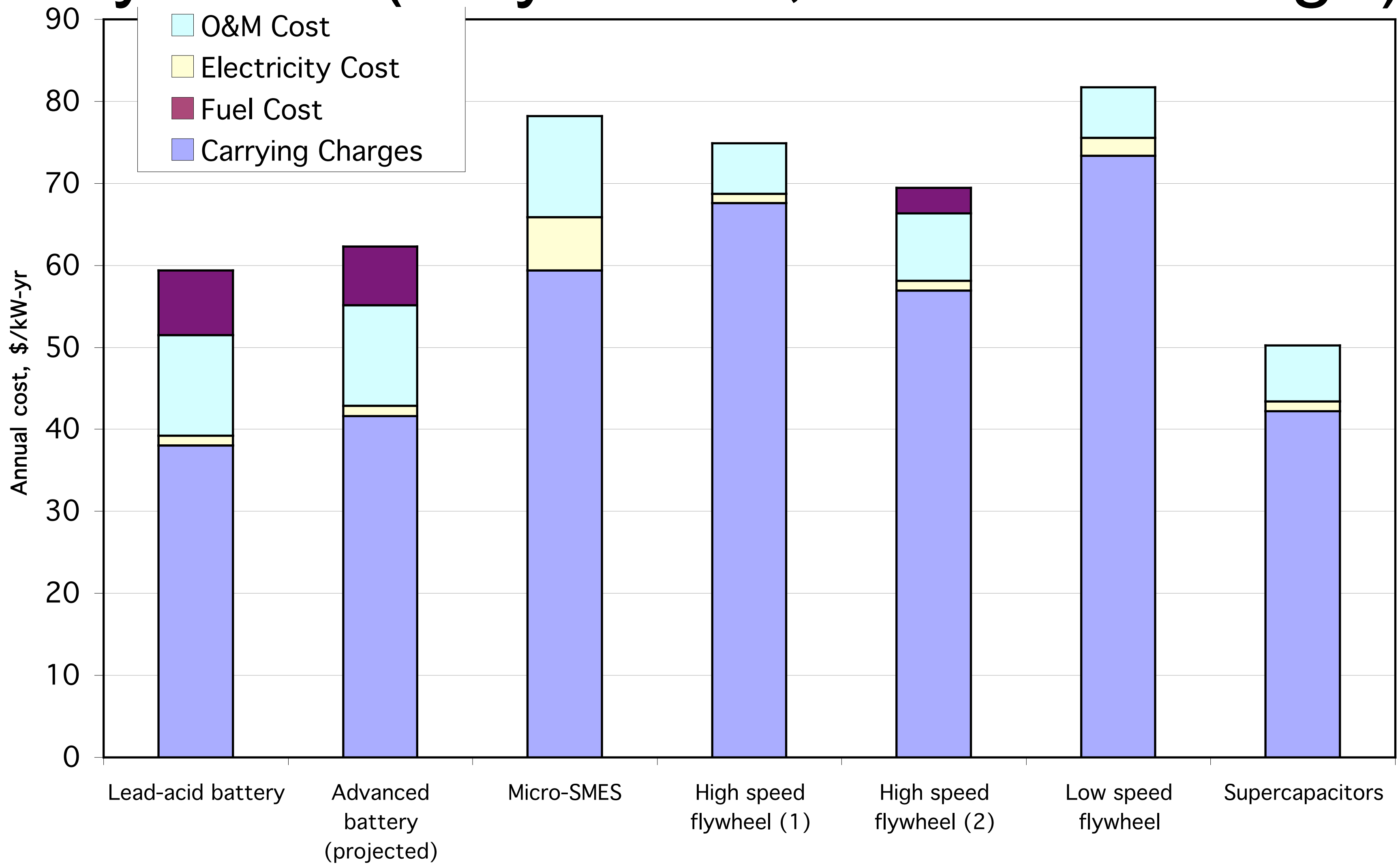
+ annualized replacement costs

+ consumables (fuel and electricity)

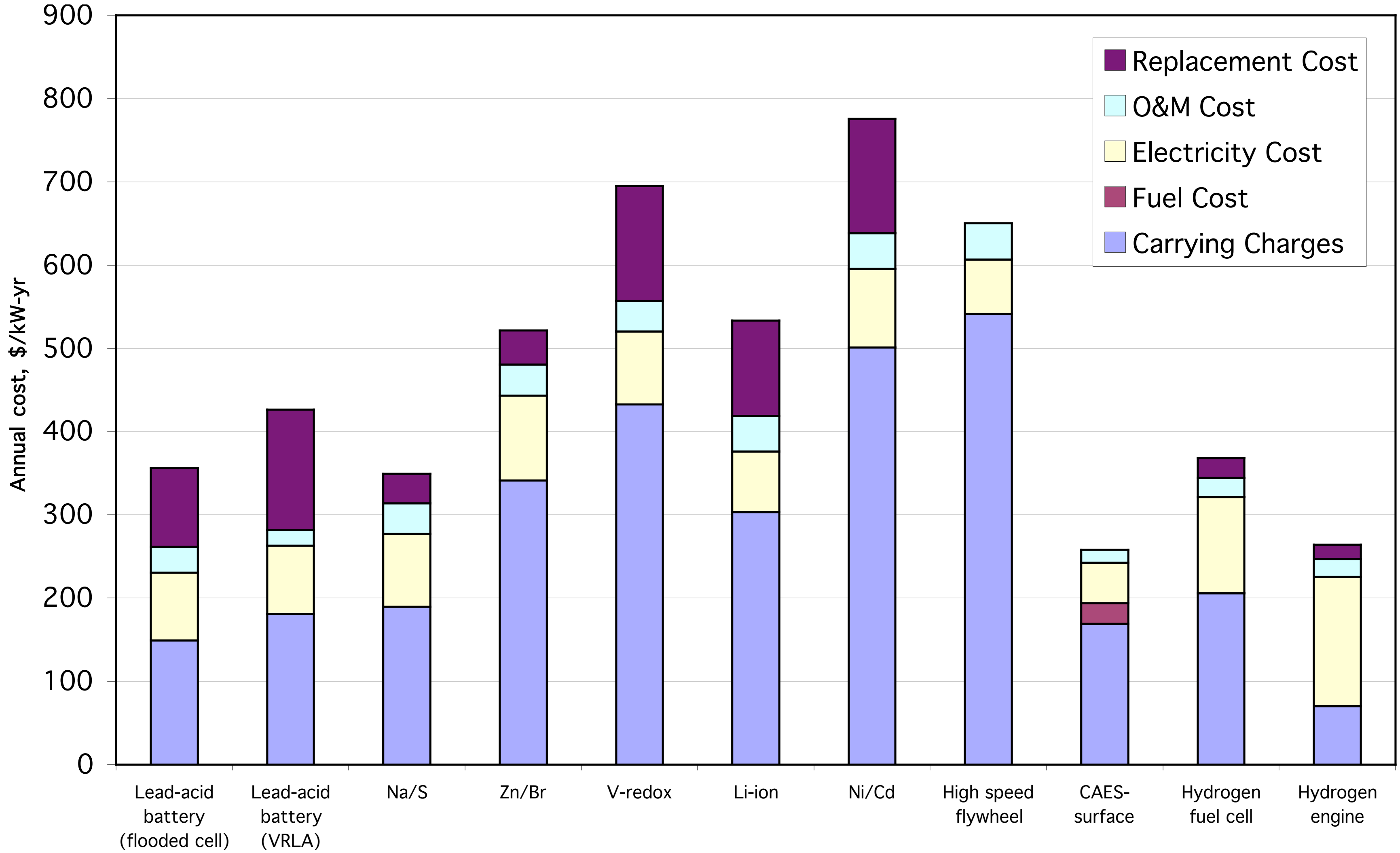
Life-cycle Cost Analysis Input

- Capital cost: power, energy, Balance-of-Plant
- Round trip efficiency, AC-AC
- Operating costs: fixed O&M, variable O&M, electricity, fuel
- Replacement frequency and costs
- Parasitic losses (e.g., cooling)
- Economic assumptions: cost of electricity, fuel, interest and inflation rates

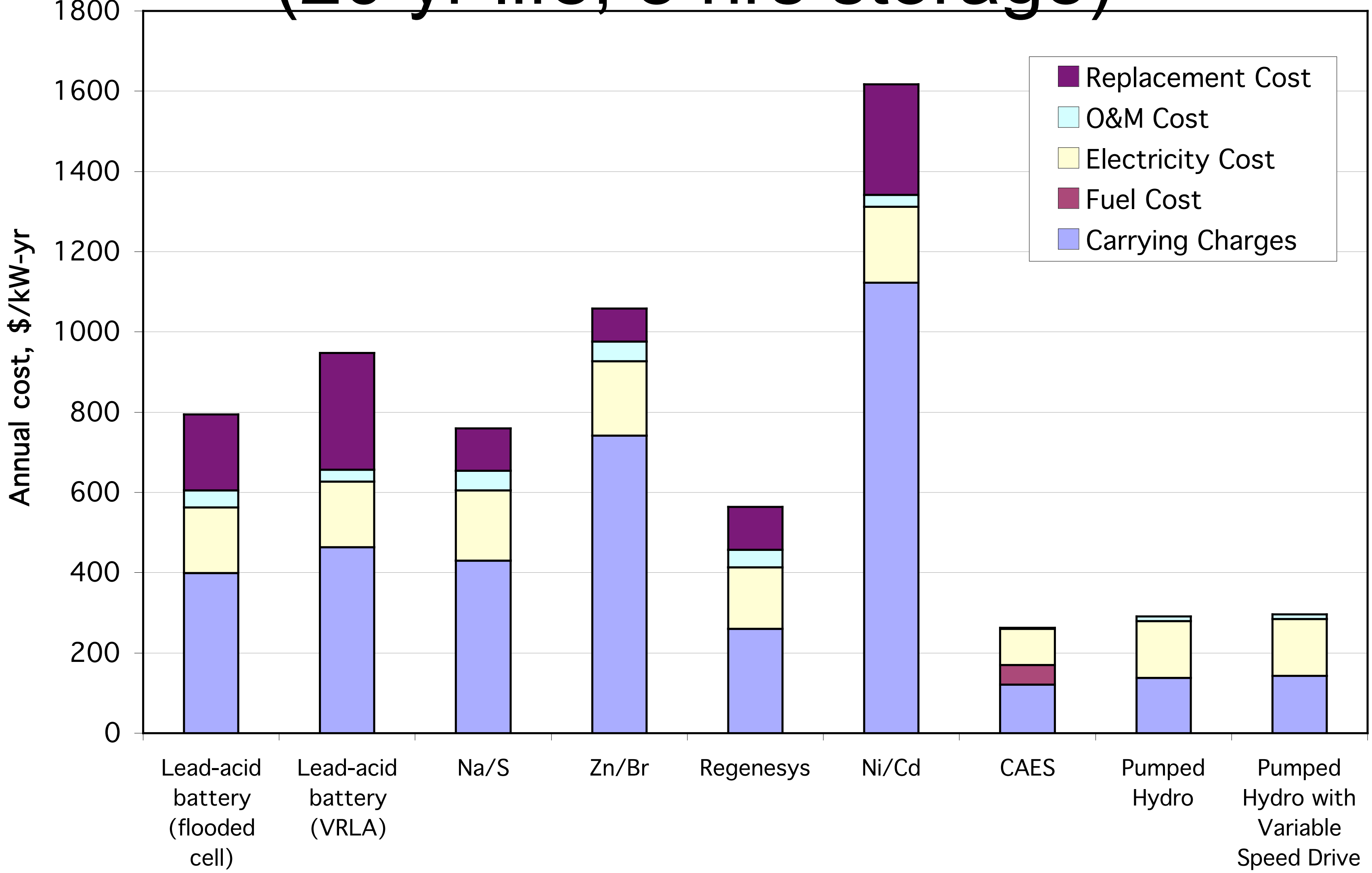
Example costs for power quality systems (10 year life, 20 secs storage)



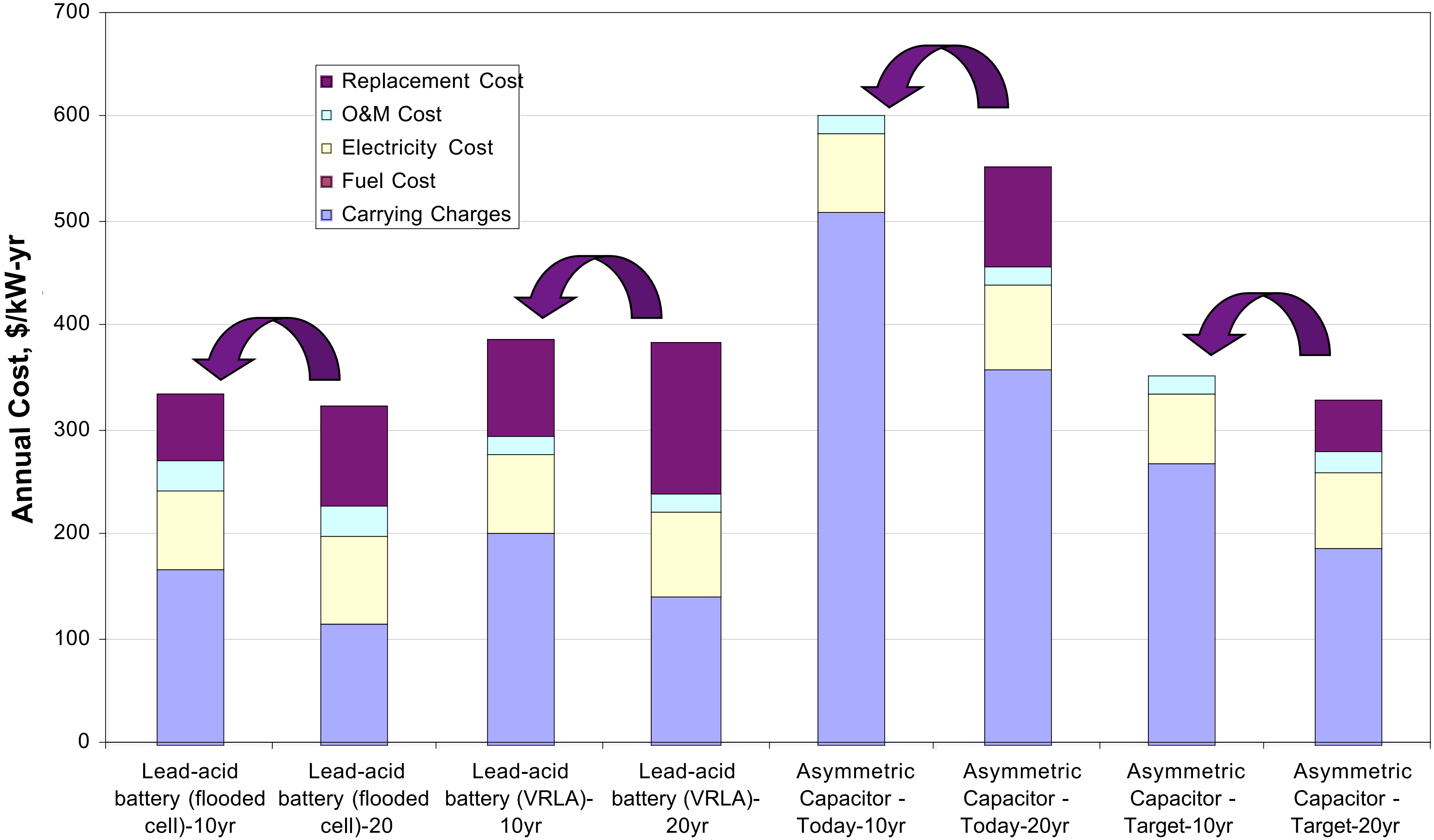
Example Annual Costs for distributed storage (10 yr life, 4 hrs storage)



Example annual cost for bulk storage (20 yr life, 8 hrs storage)



Effect of system life on replacements



Sensitivities

- Operating life: shorter payback period increases annual cost
- Number of Operating cycles: more frequent operation means more input electricity costs and possibly earlier replacement
- Replacement costs
- Energy costs (electricity, natural gas)
- Variable O&M (function of efficiency)

Present Value Cost Analysis

Makes benefit and cost bases consistent. Parameters used:

- System operating life
- Discount rate
- Escalation rate

PV factor = $$\sum_{i=1}^{10} \frac{(1+e)^{i-.5}}{(1+d)^{i-.5}}$$

e = annual price escalation rate (%/year)
d = discount rate (%/year)
i = year

Present Value Cost Analysis

Parameter	Value
General Inflation Rate	2%
Discount Rate	10%
Service Life	10 years
Utility Fixed Charge Rate	11%
Customer Fixed Charge Rate	15%
Fuel Cost, Natural Gas (surface CAES only)	$5/MBTU
Electricity Cost, Charging	10¢/kWh

Some study results - SNL*

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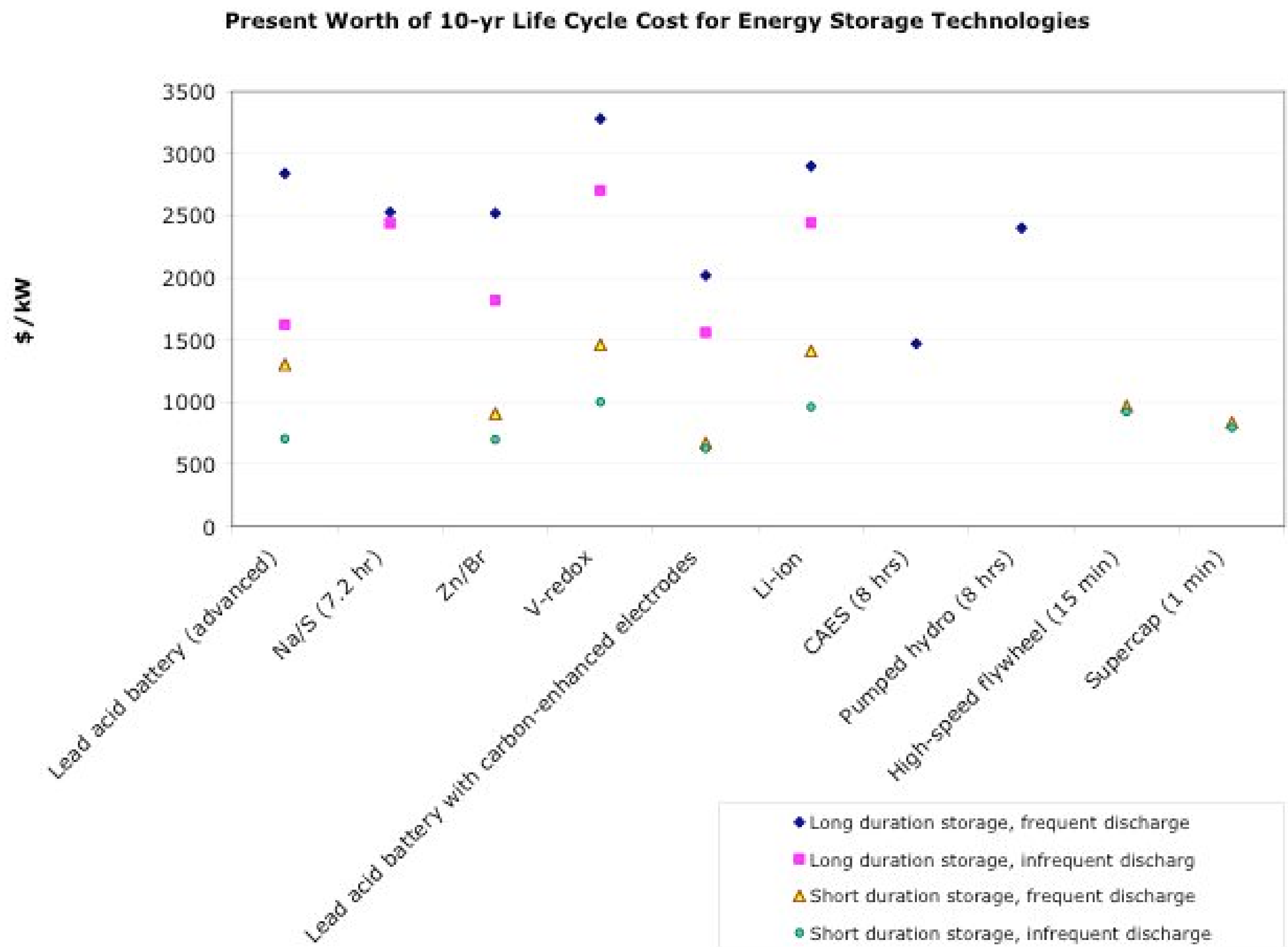


*Energy Storage Systems Cost Update: A Study for the DOE Energy Storage Systems Program

Some study results - EPRI**

Applications:

- **Wholesale Markets**
- **Wind Integration**
- **Ancillary Services**

Technology Option	Maturity	Capacity (MWh)	Power (MW)	Duration (hrs)	% Efficiency (total cycles)	Total Cost ($/kW)	Cost ($/kW-h)
Pumped Hydro	Mature	1680-5300	280-530	6-10	80-82 (>13,000)	2500-4300	420-430
		5400-14,000	900-1400	6-10		1500-2700	250-270
CT-CAES (underground)	Demo	1440-3600	180	8	See note 1 (>13,000)	960	120
				20		1150	60
CAES (underground)	Commercial	1080	135	8	See note 1 (>13000)	1000	125
		2700		20		1250	60
Sodium-Sulfur	Commercial	300	50	6	75 (4500)	3100-3300	520-550
Advanced Lead-Acid	Commercial	200	50	4	85-90 (2200)	1700-1900	425-475
	Commercial	250	20-50	5	85-90 (4500)	4600-4900	920-980
	Demo	400	100	4	85-90 (4500)	2700	675
Vanadium Redox	Demo	250	50	5	65-75 (>10000)	3100-3700	620-740
Zn/Br Redox	Demo	250	50	5	60 (>10000)	1450-1750	290-350
Fe/Cr Redox	R&D	250	50	5	75 (>10000)	1800-1900	360-380
Zn/air Redox	R&D	250	50	5	75 (>10000)	1440-1700	290-340

**Electricity Energy Storage Technology Options:A White Paper Primer on Applications, Costs and Benefits

A benefit / cost example: Modular storage

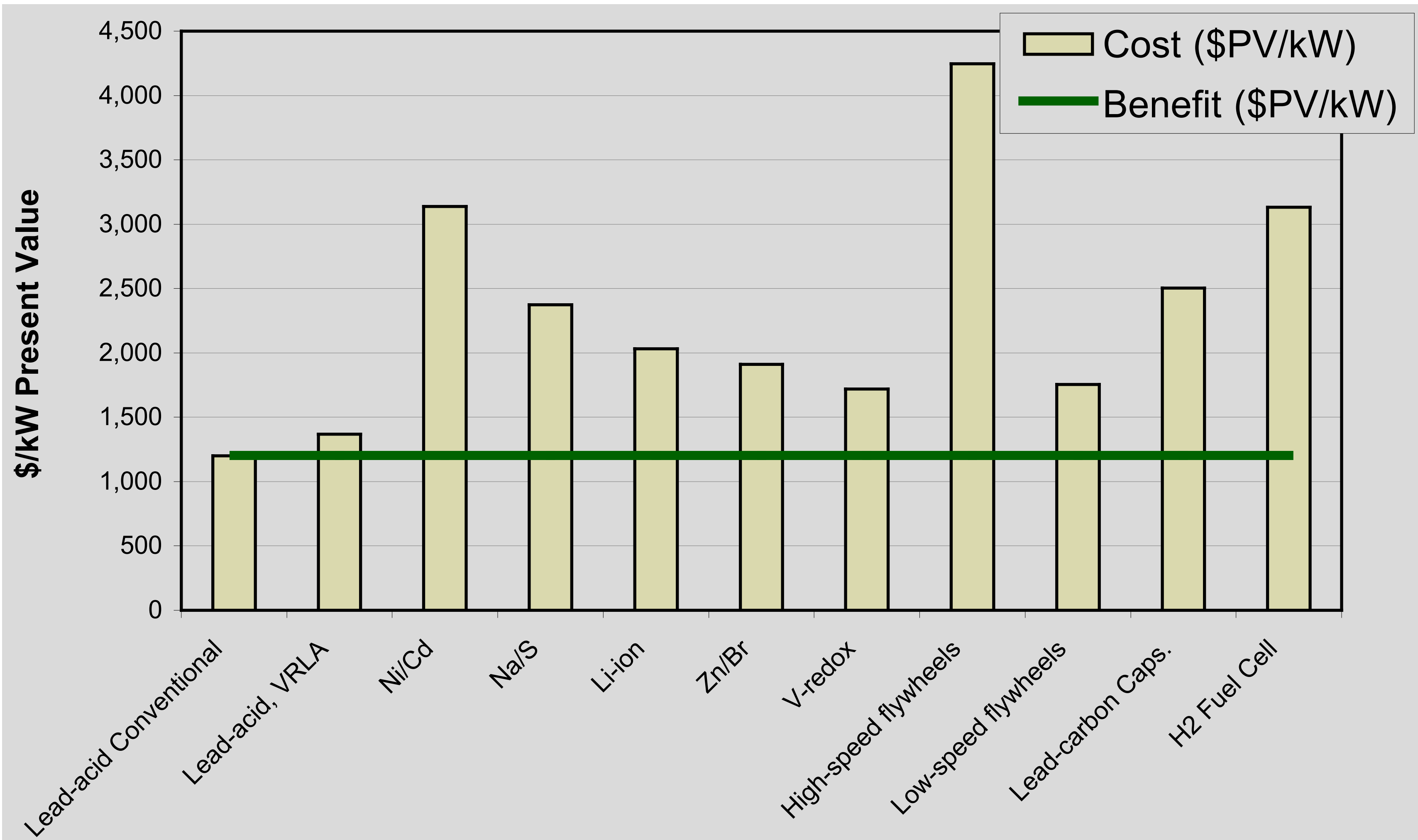
"Modular Storage Opportunities: A study for US DOE ESS Program"

T&D deferral

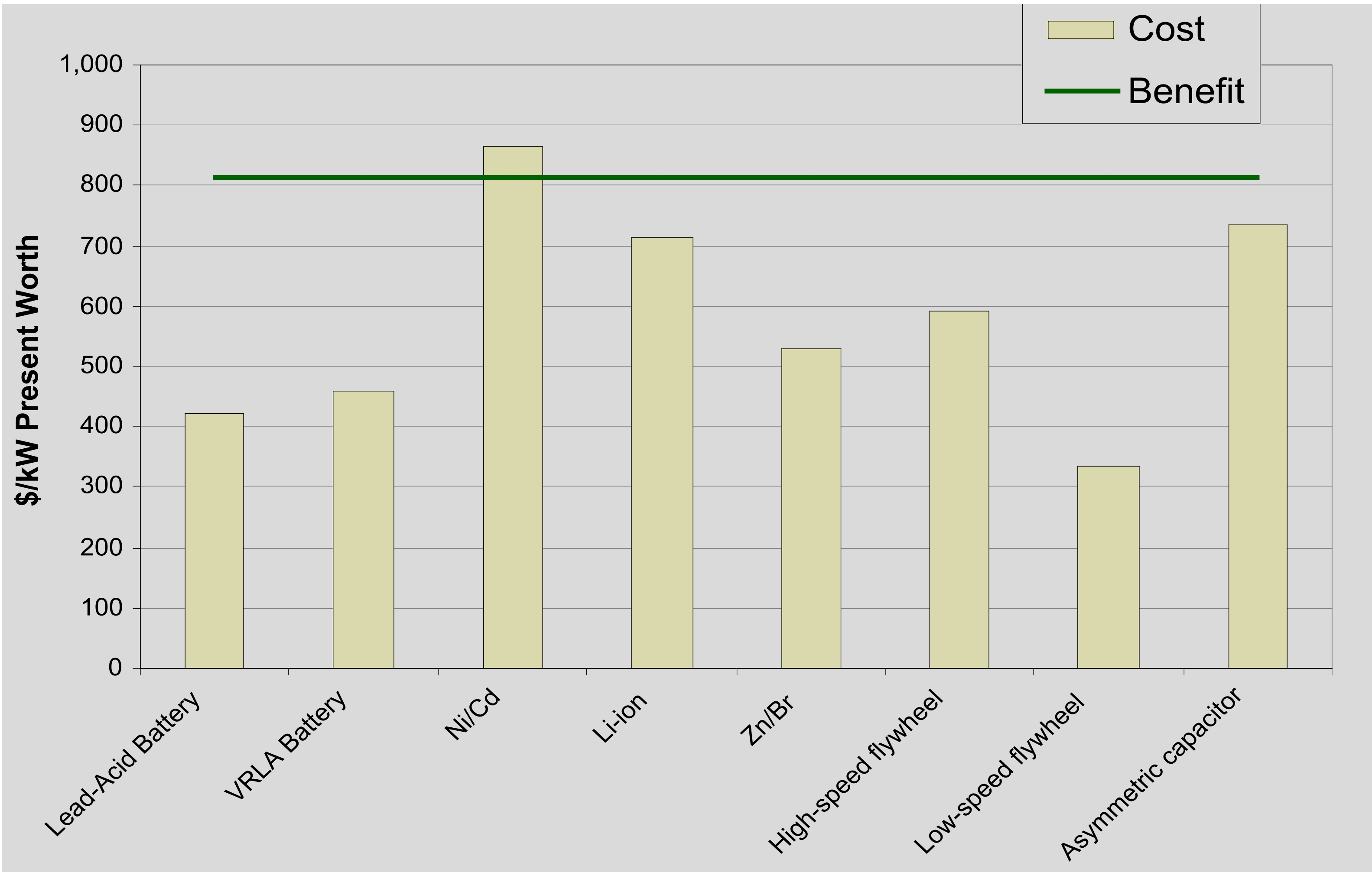
- Arbitrage
- Auxiliary services
- Power quality
- Customer peak shaving

Costs and Benefits calculated as present worth for 10-year operating life

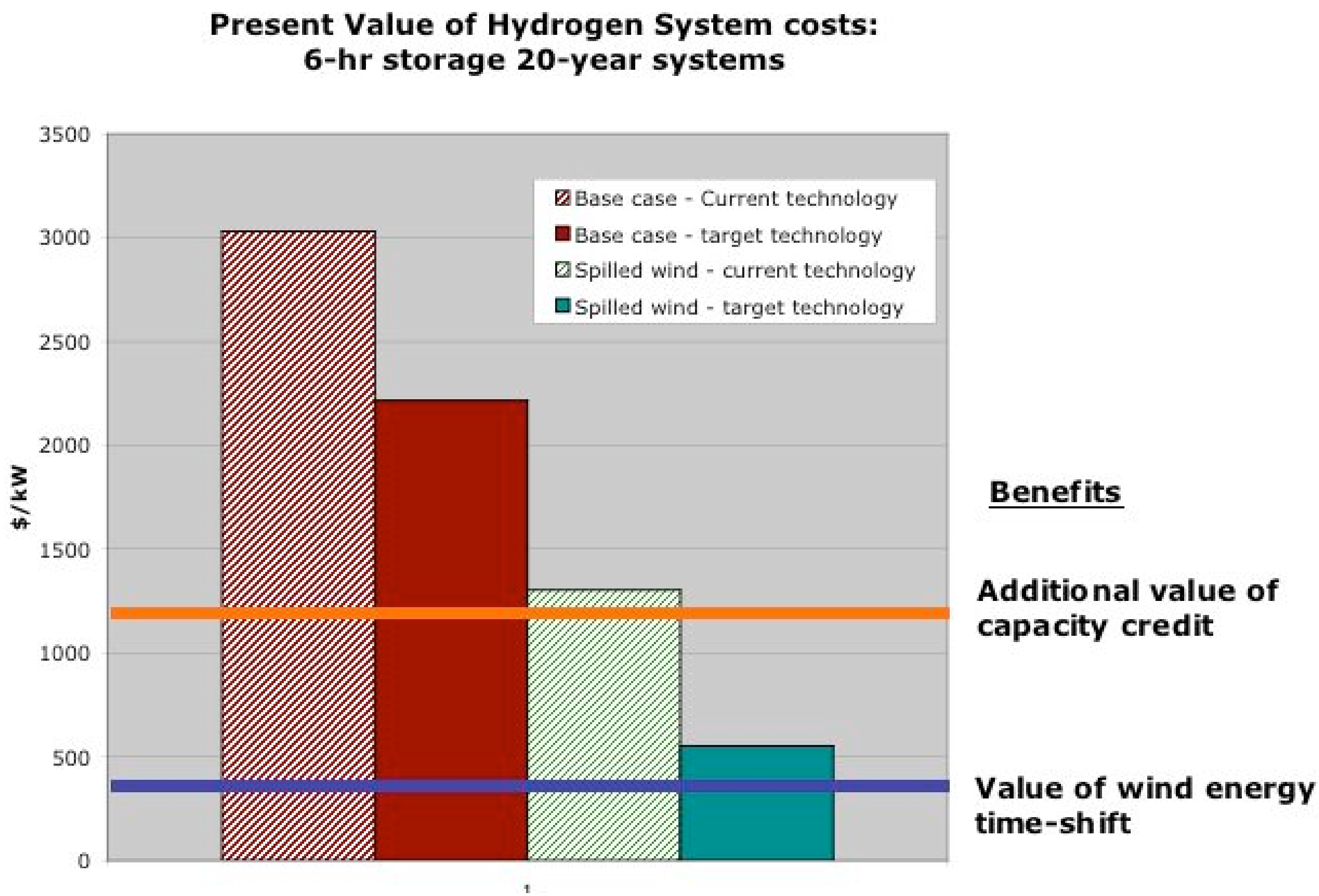
Modular Storage Opportunities: Benefit / Costs (T&D deferral)



Modular Storage Opportunities: Benefit / Costs (Power Quality)



A benefit / cost example: wind-to-hydrogen



Summary

- Long-duration dispatch => large storage => storage dominates capital cost
- Short-duration dispatch => small storage => power electronics can dominate capital cost
- Be careful of replacement costs for long term use.
- Benefit / cost value proposition difficult to generalize; need customer specifics

Conclusions

- Energy storage has an important role to play in electric power:
  - Reduced fuel use
  - Reduced emissions
  - Improved system operation and cost efficiencies
- Capital cost of technologies: potential for reduction via mass manufacturing / economies of scale
- Cycle life important for many applications
- Combined benefits ideal for system justification

Acknowledgements

- DOE Energy Storage Systems Program
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- William Hassenzahl, Advanced Energy Analysis

Thank You for Your Attention!

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