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LDES National Consortium Workshop

Long-Duration Energy Storage Cost Definition, Levelized Cost of Storge and Storage Innovations 2030

Patrick Balducci
Argonne National Laboratory
Manager, Power Systems and Markets Research

Contributors: Hill Balliet and Venkat Durvasulu, Idaho National Laboratory

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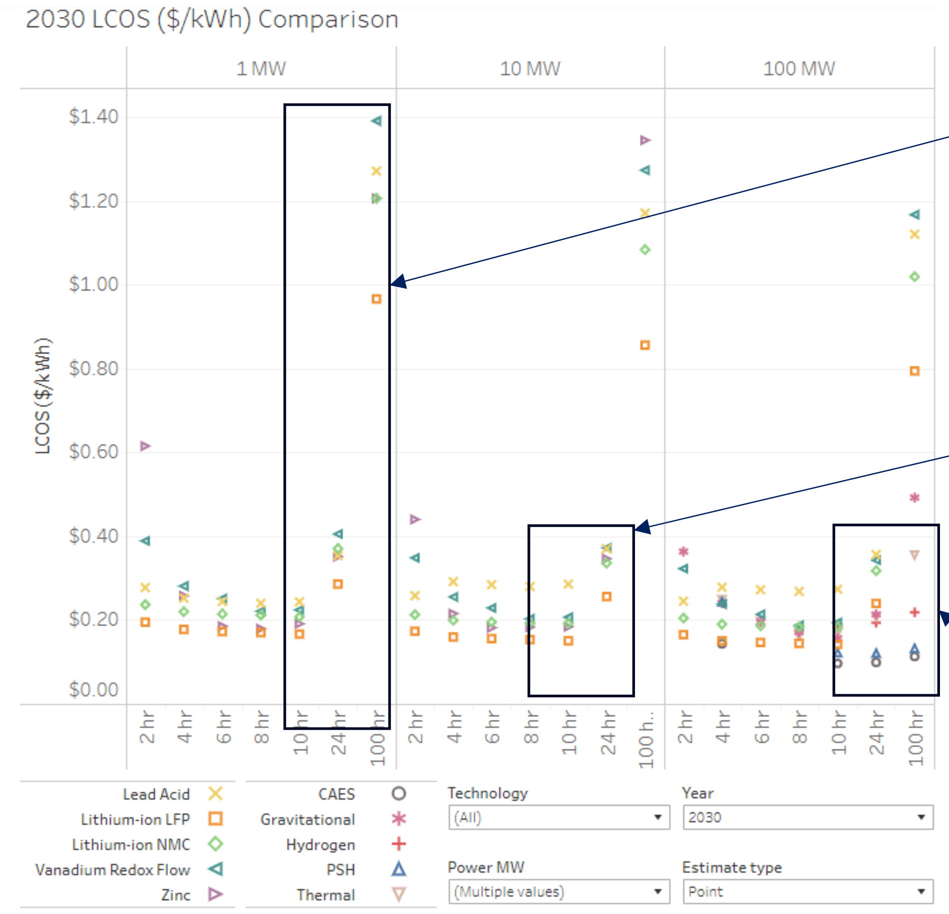
LDES Current and Forecast Cost Estimates

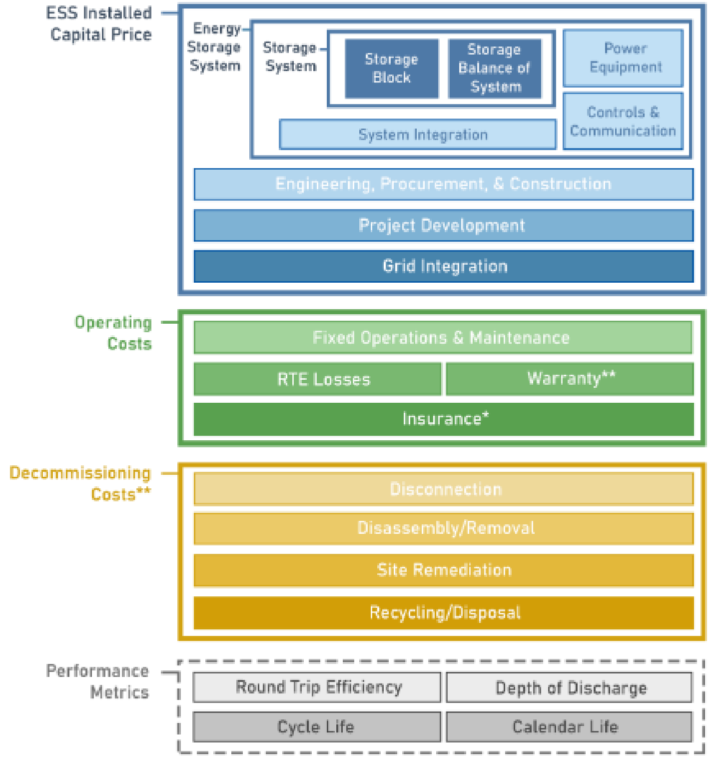


2030 LCOS Estimates by Technology

LDES pays an LCOS penalty because it cannot fully charge and discharge each day; CAPEX costs are key for LDES.

At small scale, Li-ion LFP still lower cost, even at durations => 10 hours.

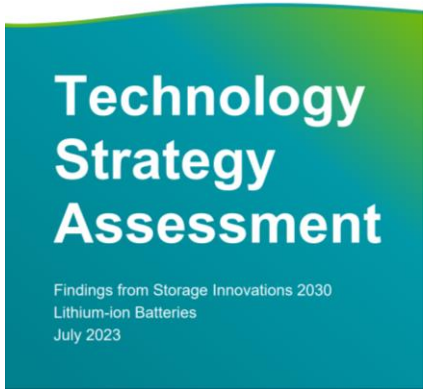
LCOS estimates reach as low as 10 cents/kWh by 2030 for PSH and CAES LDES technologies.



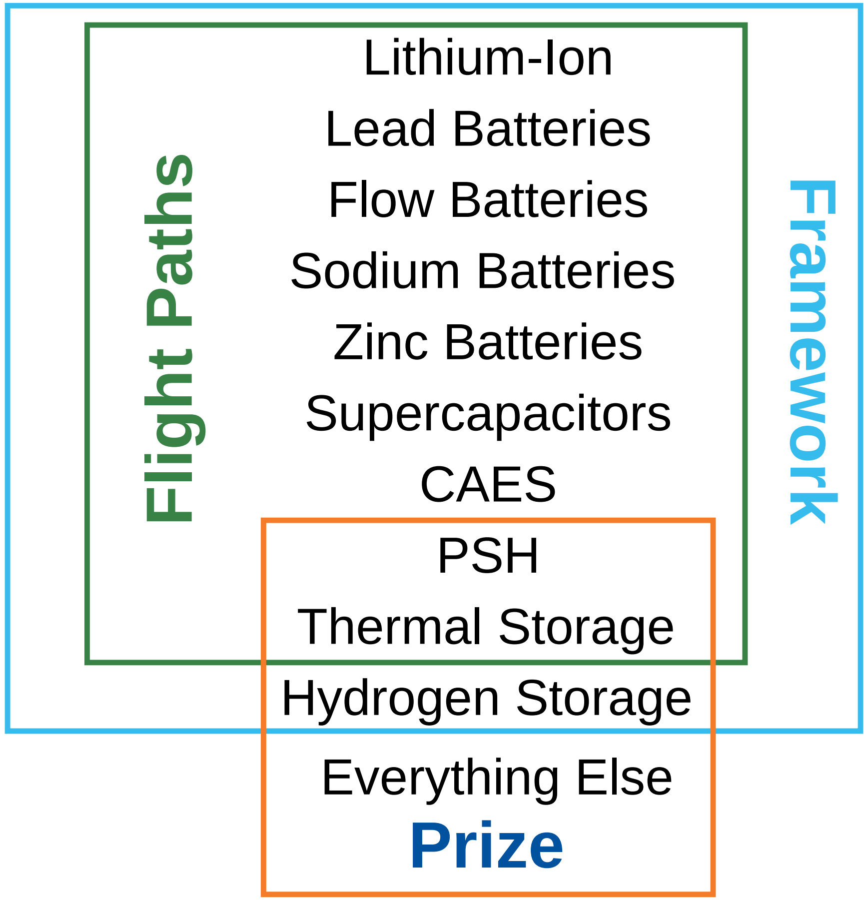
Breakdown of Cost Elements

Source: ESGC Storage Cost and Performance Database. Available at https://www.pnnl.gov/ESGC-cost-performance

Storage Innovations (SI) Technologies



Find the results of SI 2030 and technology reports at https://www.energy.gov/oe/storage-innovations-2030.



We Implemented an 8-Step Framework

Identify individual innovation opportunities

Step 1: Assess R&D trajectory status quo
Step 2: Assess gaps with respect to improving technology cost/performance
Step 3: Define interventions that could be relevant to energy storage gaps
Step 4: Assess potential impacts of investment

Assess portfolios of interventions

Step 5: Implement Monte Carlo model
Step 6: Evaluate portfolios of interventions

Analyze modeled outcomes

Step 7: Conduct suitability evaluations
Step 8: Report on metrics

Innovations Defined and Assessed through SME Interview and Follow-on Data Sharing

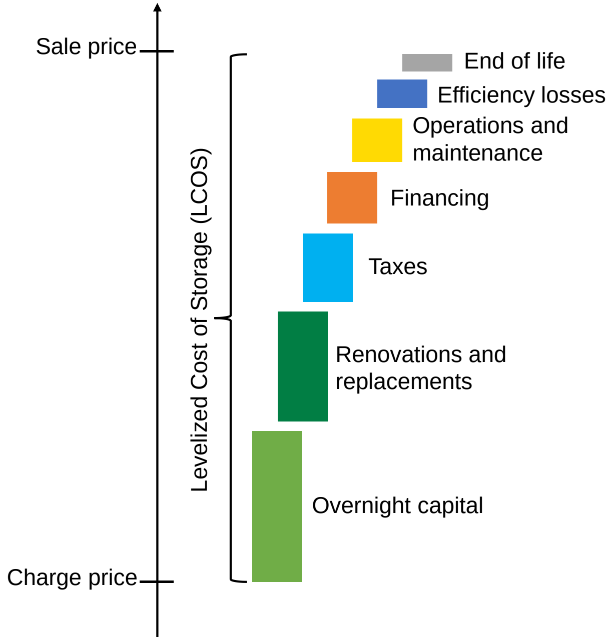
- SME Interviews
  - 24 of 24 targeted groups interviewed for lead-acid batteries
  - SMEs represented industry groups, academia, and vendors
  - Follow-on forms (suitability, investment, and impacts); 17 forms returned
  - SMEs provided input covering suitability for ESGC goals, innovation areas, R&D budgets, and impacts

Lead-Acid Battery Taxonomy of Innovations

Innovation Category	Innovation
Raw materials sourcing	Mining and metallurgy innovations
	Alloying in lead sources
Supply chain	Supply chain analytics
Technology components	Re-design of standard current collectors
	AGM-type separator
	Minimizing water loss from the battery
Manufacturing	Manufacturing for advanced lead acid batteries
Advance material development	Novel active material
	Improving paste additives - carbon
	Improving paste additives - expanders or other
	Novel electrolytes
Deployment	Scaling and managing the energy storage system
	Demonstration projects
End of life	Enhancing domestic recycling

New LCOS Formulation: Combine the Best Parts of Common Formulations to Meet Criteria

1. Show how much cost is added to electricity by storing it
2. Consider the time value of money and inflation
3. Consider taxes
4. Consider financing costs
5. Consideration of incentives like investment tax credits
6. Apply to all bidirectional electricity storage technologies
7. Inputs should be unambiguous
8. The full life cycle of the project should be included
9. Costs should be amortized over the longest practical project lifetime
10. The LCOS formula should be readily usable and easy to apply to a wide range of technologies



Build-up of LCOS

Formulation	Li-ion Result
DAYS	$0.241/kWh
LAZARD	$0.278/kWh
ESGC	$0.240/kWh
Proposed	$0.251/kWh

LCOS Results for Li-Ion

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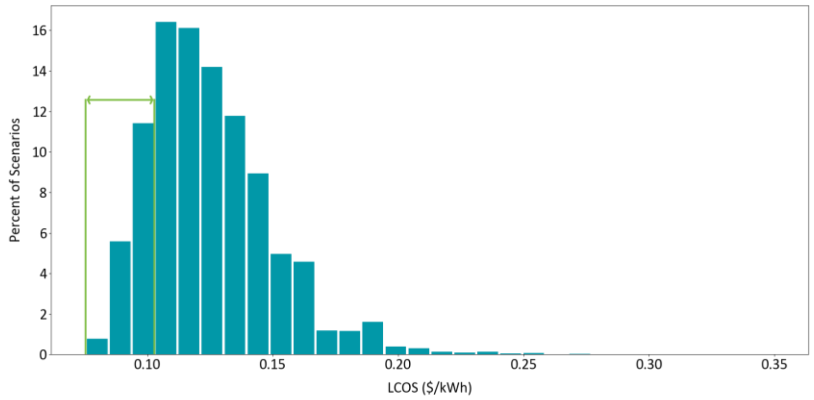
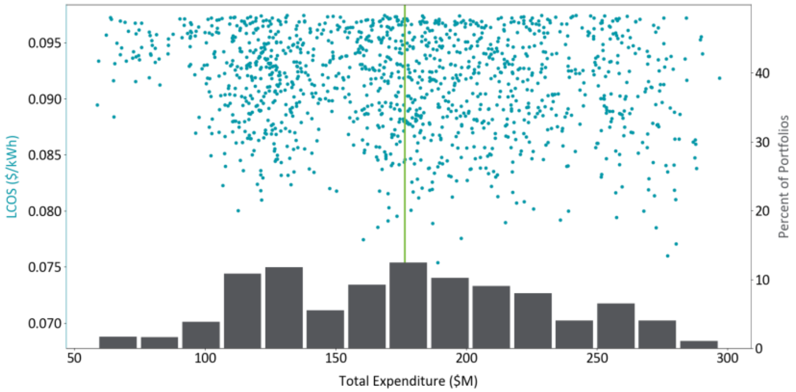
2030 Framework Study Results (Lead-Acid)

Innovation	Storage Block Cost Impact (%)	Cycle Life Improvement (%)	Round-trip Efficiency Impact (%)	Mean Investment Requirement (million $)	Mean Timeline (years)
Enhancing domestic recycling	-15% *	0% ‡	0% ‡	37.8 ‡	3.8 ‡
Demonstration projects	-24% *	75% *	11% *	26.6 ‡	3.7 †
Scaling and managing the energy storage system	-12% *	53% †	10% *	9.0 †	2.8 *
Novel electrolytes	6% †	87% *	4% †	3.9 *	3.0 *
Improving paste additives – expanders or other	8% ‡	52% †	5% †	4.5 *	3.1 †
Improving paste additives – carbon	8% ‡	63% †	3% †	3.3 *	3.1 †
Novel active materials	-15% †	102% *	7% *	5.0 *	3.7 †
Advanced manufacturing for PbA batteries	-25% *	219% *	6% *	18.4 ‡	5.5 ‡
Minimizing water loss from the battery	8% ‡	56% †	5% †	5.4 *	3.0 *
AGM-type separator	9% ‡	78% †	6% *	5.7 †	3.2 †
Re-design of standard current collectors	-21% *	125% *	5% †	8.2 †	3.0 *
Supply chain analytics	-10% †	0% ‡	0% ‡	10.5 †	2.3 *
Alloying in lead sources	10% ‡	31% ‡	0% ‡	7.7 †	4.3 ‡
Mining and metallurgy innovations	-10% †	0% ‡	0% ‡	65.7 ‡	4.2 ‡

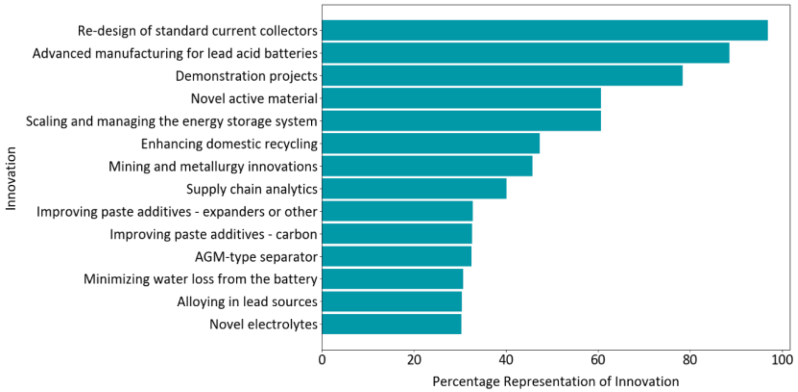
Investment Impacts by Innovation



Portfolio Frequency Distribution Across LCOS



Top 10% of Portfolios for Lead Batteries



Top Performing Innovations for Lead-Acid Batteries

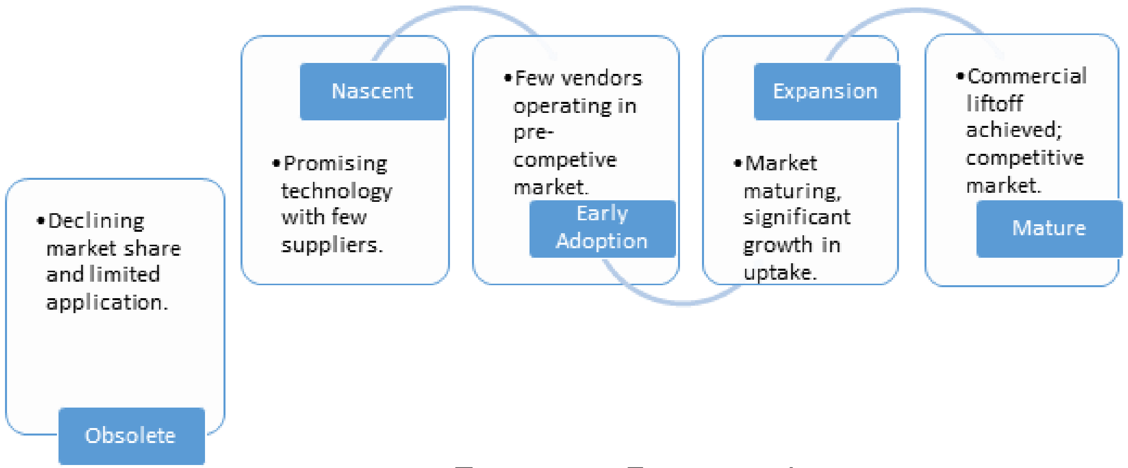
Top 3 Innovations by Technology

Technology	Innovation #1	Innovation #2	Innovation #3
CAES	Demonstration Projects	System Modeling and Design/Operation Optimization	Mechanical Compression/Expansion
Hydrogen	Liquid Hydrogen Carriers	Hydrogen Carrier Advancements	Demonstration Projects
Lead-Acid	Re-design of Standard Current Collectors	Advanced Manufacturing for Lead Acid Batteries	Demonstration Projects
Li-ion	Rapid Battery Health Assessment	Controls to Improve Cycle Life	Impurity Reduction Techniques
Sodium-ion	Cathode-electrolyte Interface	In-operation Materials Science Research	Electrolyte Development
PSH	Hybrid PSH Projects	Testing Durability of New Materials and Structures	3D Printing at Large Scale
Redox flow	Novel Active Electrolytes	Manufacturing for Scalable Flow Batteries	Accelerate Discovery Loops for Battery Metrics and Materials
Supercapacitor	Cell Packaging	Hybrid Components	Automated Manufacturing
Thermal Energy Storage	Single-tank Storage	Heat-to-electricity Conversion Improvements	Large-scale Demonstrations
Zinc	Separator Innovation	Pack/system-level Design	Demonstration Projects

- Most technologies require both basic and applied research to achieve deep LCOS reductions
- Developing technologies (e.g., redox flow and sodium-ion) require technology improvement while advanced manufacturing, control systems, and demonstration projects favored for more mature technologies

A Biannual Report to Inform Evolving Investment Opportunities: Refine List of Technologies

- SI 2030 Framework Study to be updated and published bi-annually
- Technology taxonomy framework established to systematically review and update the list of technologies
- Work more closely with industry groups
- Automate data collection process through online system
- Design website framework and layout
  - Links to current reports
  - Enable user to review and interact with key SI 2030 graphics and findings by technology
  - Advanced visualization techniques to present cross-technology results
  - Consider allowing users to query data to expand research base



Taxonomy Framework

Discussion Questions

1. What sort of information and actions on the part of DOE would benefit the industry most while pursing paths towards cost reductions and how could SI 2030 guide such investments (e.g., targeted FOA development)?
2. What would you like to see on the SI 2030 Framework Study webpage?
3. How important is it to develop a consistent LCOS definition and what improvements could we make?
4. How can we improve the quality of the information we provide?
5. How do we improve industry engagement?
6. What other information would be of most use?