Techno-Economic Pathways to Low-Cost Lead Batteries for Grid Energy Storage

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ABSTRACT

Energy storage is a critical enabler of grid reliability, resilience, and operational flexibility across a wide range of applications and operating durations. Lead-acid batteries, with their mature supply chain, recyclability, safety, and relatively low capital cost, remain a compelling option. The OE960 project establishes a pre-competitive research program to advance lead battery technologies for grid storage. As part of this effort, this work focuses on techno-economic assessment (TEA) and levelized cost of storage (LCOS) modeling to evaluate the cost and performance potential of advanced lead battery systems across diverse grid use cases, including applications with extended discharge durations. A standardized input data matrix was developed to streamline data collection from industry partners, enabling consistent representation of cost, performance, and lifetime characteristics. TEA and LCOS models were refined across multiple dimensions, considering technological advancements and system design, deployment strategies and use cases, and operational scheduling and usage patterns, to provide a holistic understanding of battery performance and economic viability. In addition, a web-based LCOS tool was developed to support transparent, scenario-driven assessments. The results provide actionable insights into cost drivers, design tradeoffs, and operational strategies that can improve the competitiveness of lead-acid batteries for grid storage.

LCOS OVERVIEW

LCOS defines a **lifetime cost** per unit of electricity **delivered** from a storage system, i.e., Lifetime cost in present value ($) / Delivered energy in present value (MWh)

$$LCOS\left[\frac{\$}{MWh}\right] = \frac{Investment\ cost + \sum_n^N \frac{O\&M\ cost}{(1+r)^n} + \sum_n^N \frac{Charging\ cost}{(1+r)^n} + \frac{End\text{-}of\text{-}life\ cost}{(1+r)^{N+1}}}{\sum_n^N \frac{Elec_{Discharged}}{(1+r)^n}}$$

- ❑ What goes into lifetime cost:
  - CAPEX: DC storage block, BOS, inverter, EPC, interconnection, controls, etc.
  - Fixed and variable O&M, replacement/augmentation, decommissioning
  - Financing: WACC/discount rate, project life, tax credits/incentives
- ❑ What drives delivered energy:
  - Round-trip efficiency (RTE), depth of discharge (DoD), # of cycles per year, dispatch profile
- ❑ Enables apples-to-apples comparison across chemistries and durations
- ❑ Shows sensitivity to cycling rate and degradation

INPUT DATA MATRICES

PROJECT PROFILE
Topic: Analytics & Tools | Vertical: Analytics
Strategic Pathway: Optimize
Project start and finish: FY25-FY27

DISPATCH STRATEGIES

- ❑ Static Duty Cycles:
  - Users define # of cycles per day, C-rate, rest period after charge/discharge
- ❑ Time-based Rules:
  - Users define when to charge and when to discharge
- ❑ Price-based Rules:
  - Charging when energy price is less than a lower threshold
  - Discharging when energy price is greater than an upper threshold
- ❑ Advanced Dispatch:
  - Employing optimization engine to determine an optimal dispatch profile based on user's selection of use cases

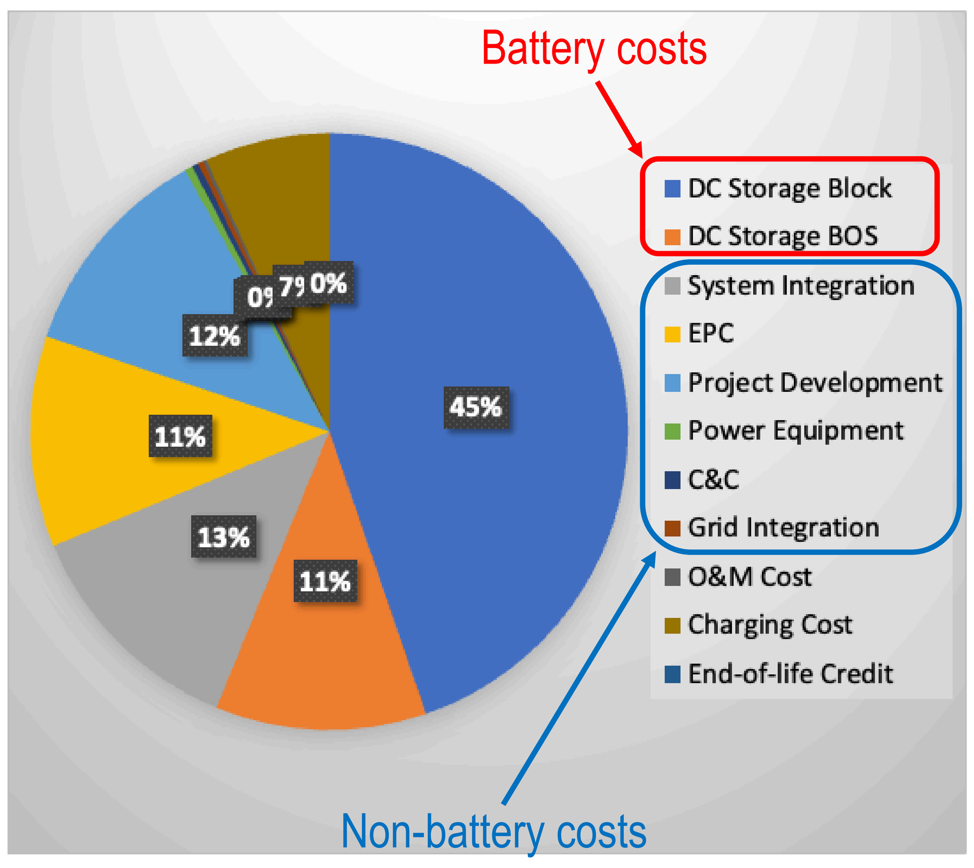
A REPRESENTATIVE EXAMPLE

Static Duty Cycles

	LCOS ($/kWh)
Including cost to charge and RTE losses	$0.50362

LCOS Breakdowns

DC Storage Block	$0.22537
DC Storage BOS	$0.05754
System Integration	$0.06329
EPC	$0.05754
Project Development	$0.05946
Power Equipment	$0.00221
C&C	$0.00173
Grid Integration	$0.00144
O&M Cost	$0.00096
Charging Cost	$0.03409
End-of-life Credit	$0.00000
Total	**$0.50362**



- ❑ The total investment cost accounts for 92% (the most dominant component)
  - Battery cost: 56%
  - Non-battery cost: 36%

POTENTIAL PATHWAYS FOR LCOS REDUCTION

- ❑ According to the LCOS formula, reducing its value requires either lowering the numerator (primarily the investment cost), increasing the denominator (the total discharged energy), or both simultaneously
- ❑ Battery components
  - Reducing DC storage block costs
  - Increasing DoD and # of cycles
  - Extending project life by augmentation
- ❑ Non-battery cost reduction
- ❑ Exploring low/negative energy prices
  - ERCOT
  - CAISO

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