Qnetic LCOS: Revolutionizing Energy Storage Economics

Call to Action: For stakeholders, investors, and energy providers looking to enhance the economics of renewable energy storage, this white paper outlines why Qnetic is the ideal solution that aligns with market needs and global climate goals.

Revision History:

Version	Date	Description
Rev 1	2024-12-05	White paper creation

1 Table of Contents

2 Executive Summary

Energy storage is at the heart of the renewable energy revolution, enabling the transition to a cleaner, more resilient energy grid. As renewable sources like wind and solar continue to grow, the need for cost-effective, long-duration energy storage has never been greater. One of the most critical metrics for evaluating storage solutions is the **Levelized Cost of Storage (LCOS)**, which captures the true economic efficiency of energy storage over its lifetime.

Qnetic is developing a revolutionary kinetic energy storage system that is expected to deliver a significantly lower LCOS compared to traditional energy storage technologies, including lithium-ion batteries, flow batteries, and pumped hydro. By leveraging innovative design, cutting-edge materials like high-tech carbon fiber, and a highly automated manufacturing process, Qnetic is creating a durable, scalable, and cost-efficient solution.

Key advantages of Qnetic’s system that contribute to its low LCOS include:

- **Zero Degradation**: Unlike lithium-ion batteries, Qnetic’s system experiences no capacity fade over decades of daily cycling, eliminating costly replacements.
- **High Efficiency**: With expected round-trip efficiency from grid to grid of 85%, energy losses are minimal, maximizing value.
- **Cost-Effective Materials**: The use of advanced but affordable materials, combined with streamlined manufacturing processes, reduces capital and operational costs.
- **Long Operational Life**: Qnetic’s rotor is engineered for reliability, providing decades of service with minimal maintenance.

This white paper provides a detailed exploration of Qnetic’s LCOS, demonstrating how our technology outperforms competing solutions economically.

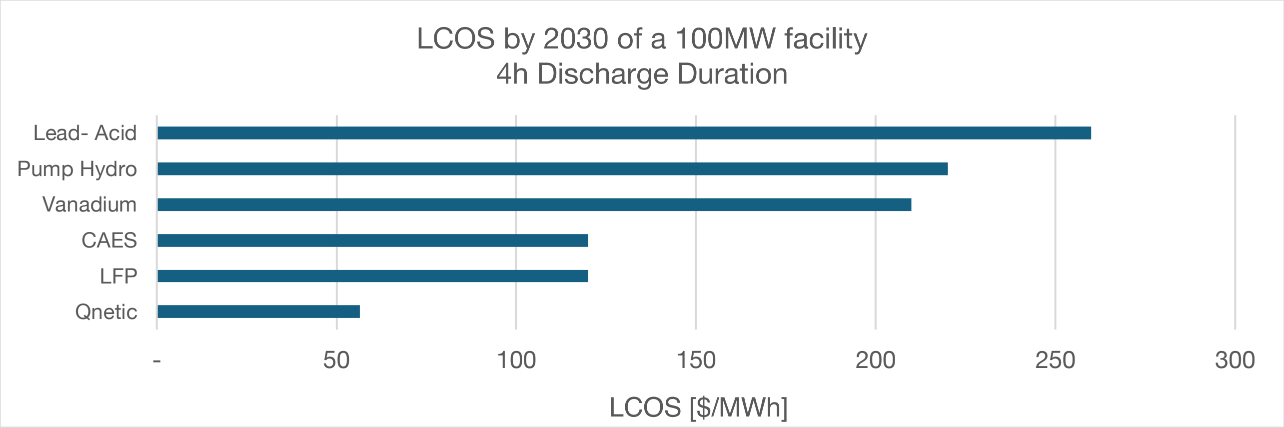


Figure 1: LCOS of competing technologies for a 100MW facility and 4h discharge duration.

Source*: Qnetic Corporation for Qnetic LCOS; https://www.pnnl.gov/projects/esgc-cost-performance/lcos-estimates for all other technologies.*

3 Introduction to LCOS

3.1 LCOS Definition

> *"LCOS represents a cost per unit of discharge energy throughput ($/kWh) metric that can be used to compare different storage technologies on a more equal footing than comparing their installed costs per unit of rated energy. Different systems have different calendar life, cycle life, depth of discharge (DOD) limitations, and operations and maintenance (O&M) costs and may require various capital expenditures over time in the form of augmentations, replacements, and major overhauls (ARMO). Each of these characteristics and parameters, in addition to taxes, costs due to debt, and others, ultimately determines the total revenue requirements of a storage system over the lifetime of a project."*

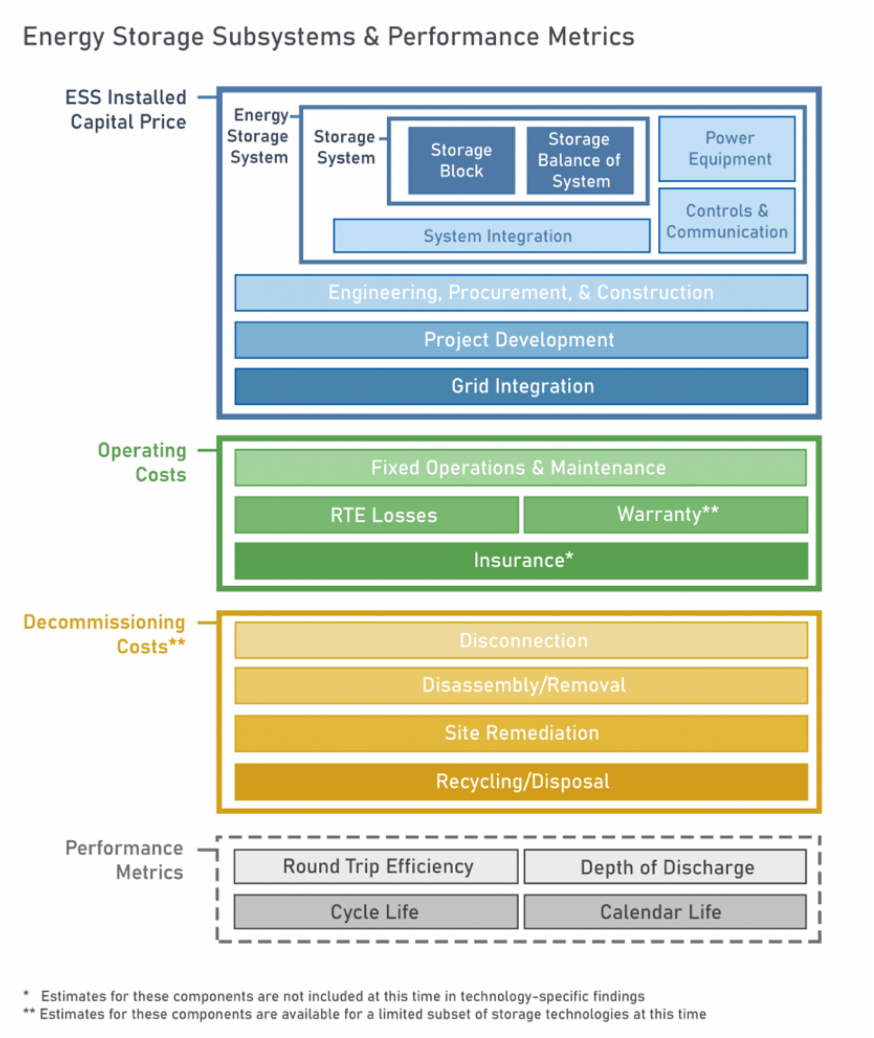
Definition extracted from Pacific Northwest National Laboratory Website.

The Pacific Northwest National Laboratory (PNNL) is a U.S. national laboratory that has taken the lead in comparing energy storage costs across various technologies as part of the Energy Storage Grand Challenge (ESGC) managed by the Department of Energy (DOE). In 2022, the ESGC and DOE released a comprehensive report titled *"2022 Grid Energy Storage Technology Cost and Performance Assessment,"* authored by Vilayanur Viswanathan, Kendall Mongird, Ryan Franks, Xiaolin Li, and Vincent Sprenkle from PNNL, along with Richard Baxter from Mustang Prairie Energy. We are using this report as a reference for the Levelized Cost of Storage (LCOS) calculation of our system to make an apples-to-apples comparison with the other technologies presented in the PNNL report.

In 2024, PNNL updated its database with cost data for various energy storage technologies, which are available on their website: https://www.pnnl.gov/projects/esgc-cost-performance/lcos-estimates. In this update, PNNL provides a breakdown of storage technology costs along with projections for these costs by 2030. There are three estimates provided for this projection: HIGH, POINT, and LOW. The LOW estimate reflects the lowest cost projection, and we have systematically chosen this estimate for our comparison.

3.2 Energy Storage Subsystems and Definitions

According to PNNL methodology the energy storage costs are broken down as followed.



* Estimates for these components are not included at this time in technology-specific findings
** Estimates for these components are available for a limited subset of storage technologies at this time

Figure 2: Energy storage subsystems and performance metrics.

Source: *https://www.pnnl.gov/projects/esgc-cost-performance/subsystems-definitions*

3.3 Technologies compared

Several technologies compete in the US energy storage market. They all have their specificities, advantages and drawbacks. In this study we are considering the following technologies:

Source: *https://www.pnnl.gov/projects/esgc-cost-performance/estimates*

3.3.1 Lithium-ion LFP

Lithium-ion can refer to a wide array of chemistries; however, it ultimately consists of a battery based on charge and discharge reactions from a lithiated metal oxide cathode and a graphite anode. Lithium-ion batteries are used in a variety of ways, from electric vehicles to residential batteries to grid-scale applications. Two lithium-ion chemistries—Nickel Manganese Cobalt (NMC) and

Lithium Iron Phosphate (LFP)—are more commonly found in the industry. However, the LFP technologies are more commonly used in grid energy storage because they are cheaper and have a longer cycle life than their counterpart NMC.

3.3.2 Lead Acid Battery

Lead acid batteries are made up of lead dioxide (PbO_2) for the positive electrode and lead (Pb) for the negative electrode. Vented and valve-regulated batteries make up two subtypes of this technology. This technology is typically well-suited for larger power applications.

3.3.3 Vanadium Redox Flow Battery

The flow battery is composed of two tanks of electrolyte solutions, one for the cathode and the other for the anode. Electrolytes are passed by a membrane and complete chemical reactions to charge and discharge energy. The technology is still in the early phases of commercialization compared to more mature battery systems such as lithium-ion and lead-acid. Scalability due to modularity, the ability to change energy and power independently, and long cycle and calendar life are attractive features of this technology.

3.3.4 Pumped Storage Hydropower

Pumped storage hydro (PSH) is a mature technology that includes pumping water from a lower reservoir to a higher one where it is stored until needed. When released, the water from the upper reservoir flows back down through a turbine and generates electricity. There are various configurations of this technology, including open-loop (when one or more of the reservoirs are connected to a natural body of water) and closed-loop (when both reservoirs are separate from natural waterways). Existing turbine technologies also offer different features and capabilities, including fixed speed, advanced speed, and ternary.

3.3.5 Compressed Air Energy Storage

This energy storage system involves using electricity to compress air and store it in underground caverns. When electricity is needed, the compressed air is released and expands, passing through a turbine to generate electricity. There are various types of this technology including adiabatic systems and diabatic systems. The difference between these two configurations is that adiabatic systems capture and store the heat generated through the compression process to re-use later in the air expansion process to generate a larger amount of power output. For diabatic systems, the heat generated during compression is simply released. Newer applications of this technology include the development of isothermal CAES. This technology attempts to utilize a different process by removing heat across multiple stages of compression to reach a temperature closer to ambient, making it easier and more economical to store.

3.4 LCOS Calculations hypothesis.

3.4.1 The Lithium-ion LFP Cell cost

Lithium-ion energy storage systems consist of several key subsystems:

- **Storage Block:** This refers to the battery cell pack, which is predominantly supplied by manufacturers in China.
- **Balance of the System (BOS):** This includes components such as the container, cabling, switchgear, and HVAC systems. For the U.S. market, these components are typically sourced from domestic suppliers.
- **Power Equipment:** This encompasses all systems necessary for power conversion and the DC-DC converter, which are provided by U.S. companies.
- **Controls and Communication:** This subsystem consists of the controls and energy management systems, which are also sourced domestically.
- **System Integration:** This aspect is managed by domestic providers as well.

According to PNNL.gov, for a 100 MW project with a 4-hour duration in 2030, the low estimate for the energy storage subsystem cost of a Lithium-ion LFP battery is as follows:

- **The Storage Block:** 107.43 $/kWh
- **The Balance of the System (BOS):** 24.80 $/kWh
- **Power Equipment:** 45.17 $/kW or 11.29 $/kWh
- **Controls and Communication:** 0.83 $/kW or 0.21 $/kWh
- **System integration:** 30.45 $/kWh

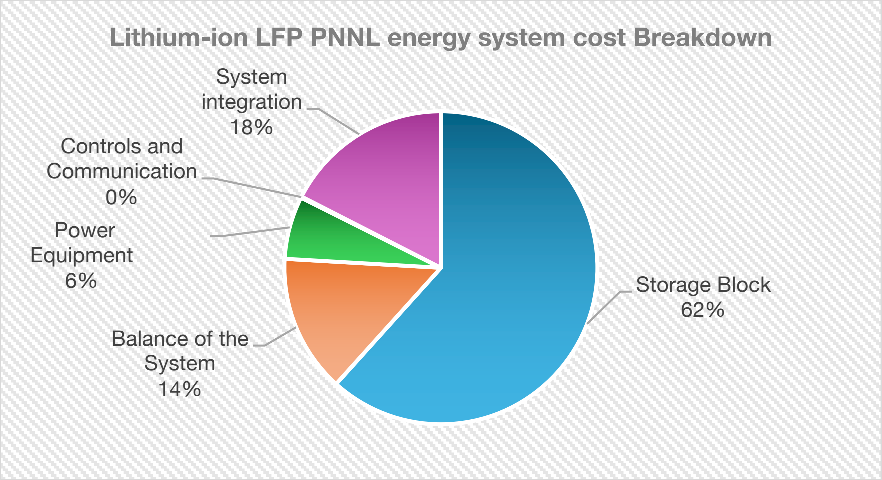


Figure 3: Energy storage subsystems cost breakdown according to PNNL data.

***Source**: https://www.pnnl.gov/projects/esgc-cost-performance/lithium-ion-battery*

Some argue that the current prices of Chinese storage blocks are significantly lower than the estimates from the Pacific Northwest National Laboratory (PNNL). Indeed, China's strategy to saturate the market with inexpensive lithium-ion batteries has created artificially low prices for these cells. Additionally, the U.S. is currently responding to this situation. On May 14th, 2024, the

Biden Administration announced changes to Section 301 tariffs on Chinese products. Specifically, for energy storage, the tariffs on Chinese lithium-ion batteries for non-electric vehicle applications will increase from 7.5% to 25%, more than tripling the tariff rate. This increase is set to take effect in 2026. There is also a general tariff of 3.4% applied to lithium-ion battery imports. As a result, the total tariff that importers will pay will rise from 10.9% to 28.4%.

Given this context, predicting the cost of lithium-ion storage blocks by 2030 is challenging. To provide a lower cost estimate than PNNL's prediction, we evaluated the Levelized Cost of Storage (LCOS) for Very Low Cell Cost of Lithium Iron Phosphate (Li-ion LFP VLCC). While **PNNL** predicts the storage blocks will cost **$107.43 per kilowatt-hour (kWh),** our estimate for the **Li-ion LFP VLCC** case is reduced to **$50 per kWh**.

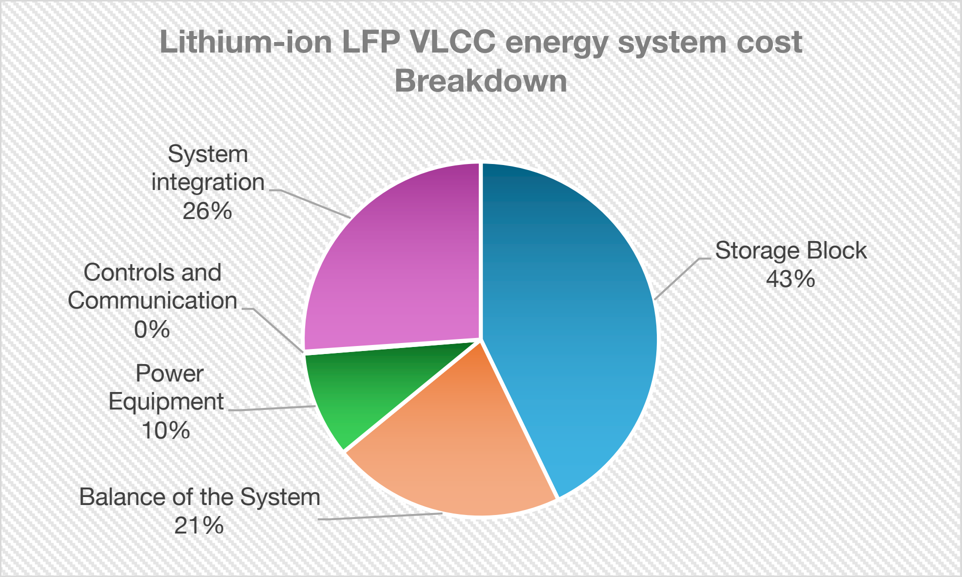


Figure 4: Energy storage subsystems cost breakdown according to our Very Low Cell Cost approach.

3.4.2 Cost breakdown per technology

100MW / 2030 / Low estimate / 4h	Qnetic	Li-ion LFP PNNL	Li-ion LFP VLCC*	Lead Acid	Vanadium Redox	Pump Hydro	CAES
Energy Storage System Cost [$/kWh]	85	163	105	275	365	70	3
Power System Cost [$/kW]	60	46	46	65	84	2,152	945
EPC & Project Development [$/kWh]	103	68	68	60	98	-	-
Grid Integration [$/kW]	15	15	15	15	15	-	-
Operating Costs [$/kW-year]	3	3	3	4	5	24	15
Decommissioning Costs [$/kWh]	-	-	-	14	26	-	-
RTE [%]	85	85	85	77	65	80	65
Self-discharge per cycle [%]	2.26	-	-	-	-	-	-
Calendar Life [yrs]	30	16	16	14	12	60	60
Primary DOD [%]	100	80	80	68	80	80	80
Cycle life at primary DOD	22,000	5,005	5,005	2,368	5,250	-	-
Secondary DOD or EOL [%]	-	60	60	60	80	-	-
Cycle life at secondary DOD	-	9,100	9,100	-	-	-	-

Energy Storage System Cost [$/kWh]: Include storage block, BOS, Controls & Communications, and System integration.
Power System Cost [$/kW]: Bi-directional inverter, DC-DC converter, isolation protection, alternating current (AC) breakers, relays, communication interface, and software. This is the power conversion system for batteries, the powerhouse for PSH, and the power island/powertrain for CAES.
EPC & Project Development [$/kWh]: Includes non-recurring engineering costs, construction equipment, and shipping, siting, installation & commissioning of the ESS; cost is weighted based on duration. It also includes costs associated with permitting, power purchase agreements, interconnection agreements, site control, and financing
Grid Integration [$/kW]: Direct cost associated with connecting the ESS to the grid, including transformer, metering, and isolation breakers. It could be a single disconnect breaker or a breaker bay for larger systems.
Operating Costs [$/kW-year]: All costs necessary to keep the storage system operational throughout its life; costs, such as planned maintenance, parts, labor, and benefits for staff, do not fluctuate based on energy throughput. Also includes major overhaul-related maintenance, which depends on throughput.
Decommissioning Costs [$/kWh]: Costs associated with the disconnection, disassembly, removal, and site remediation. These costs may vary widely based on whether the ESS is in the built environment or outside the built environment, how far materials must be transported, and whether site remediation is necessary.
RTE [%]: Round-trip efficiency is simply the ratio of energy discharged to the grid from a starting state of charge to the energy received from the grid to bring the ESS to the same starting state of charge. RTE is < 1 due to the following losses - thermal management, electrochemical, power conversion, powertrain, energy conversion, evaporation, or gas/air leakage.
Self-discharge per cycle [%]: refers to the rate at which it loses stored energy over time due to friction from bearings, air resistance within the vacuum enclosure, and other mechanical losses
Calendar Life [yrs]: The maximum life of the system, regardless of operating conditions. For batteries, calendar life depends on the ambient temperature and state of charge (SOC).
Cycle life at primary and secondary DOD: The cycle life for an ESS is a function of depth of discharge and is the total number of cycles that an ESS can provide at any depth of discharge over its life.
Primary, Secondary DOD or EOL [%]: DoD (Depth of Discharge) refers to how much of a battery’s energy has been drained, expressed as a percentage. EOL (End of Life) in percentage refers to the minimum DOD before the battery is considered dead.

Source: *https://www.pnnl.gov/projects/esgc-cost-performance/subsystems-definitions*

Table 1: Cost breakdown per technology for a 100MW project, 4h duration, low estimate projections by 2030

3.4.3 General parameters used in LCOS calculation

Common variables	**Value**
Electricity purchase price [USD/kWh_el]	0.03
Price escalator [%]	0%
Nominal rated capacity - power [kW]	100,000
Discount rate [%]	5%
Construction start [year]	2030
Estimate Type (PNNL DATA)	Low

Electricity purchase price: the LCOS accounts for the cost of the electricity to charge the system. As the electrical energy should mostly come from solar and wind this cost is estimated at 0.3$/kWh

Price escalator: a mutually agreed-upon price increase in a contract that accounts for anticipated cost increases over the contract's life. It is 0% in this study.

Nominal rated capacity - power [kW]: size of the project in kW. It corresponds to the nameplate power.

Discount rate: the rate of return used to discount future cash flows back to their present value.

Construction start: the year when the project construction starts.

Estimate Type (PNNL DATA): price estimate project in 2030. LOW is the lowest projected cost.

Table 2: Common variables of the LCOS model

4 The Qnetic Battery

4.1 Qnetic introduction

Qnetic's energy storage system is a revolutionary kinetic battery that uses flywheel technology. It is designed for long-duration storage with unmatched efficiency and durability. At its core is a patented rotor made from advanced materials like high-tech carbon fiber, ensuring zero capacity fade over decades of operation.

With a round-trip efficiency of 85%, Qnetic provides a cost-effective and sustainable alternative to traditional batteries. Its modular design is scalable for various applications, from renewable energy integration to grid stabilization.

By minimizing maintenance, maximizing lifecycle performance, and using environmentally friendly materials and production methods, Qnetic is specifically designed to meet the energy storage demands of 4 to 12-hour durations, a critical range for integrating renewables into the grid. This range effectively addresses the intermittent nature of solar and wind energy, ensuring that excess energy generated during peak production can be stored and reliably dispatched when needed, stabilizing supply and demand.

The technical characteristics of a Qnetic battery are:

- Capacity: 1,000kWh
- Power output: 250kW
- Round trip efficiency: 85%
- Total mass: 20 tonnes

4.2 Qnetic Cost Breakdown

The cost of Qnetic is broken into two parts. The equipment cost capex and the installation capex.

100MW / 2030 / Low estimate / 4h	Qnetic
ESS equipment cost capex [$/kWh]	100
Fully installed capex [$/kWh]	207

Table 3: Qnetic cost breakdown

4.2.1 Qnetic Equipment cost

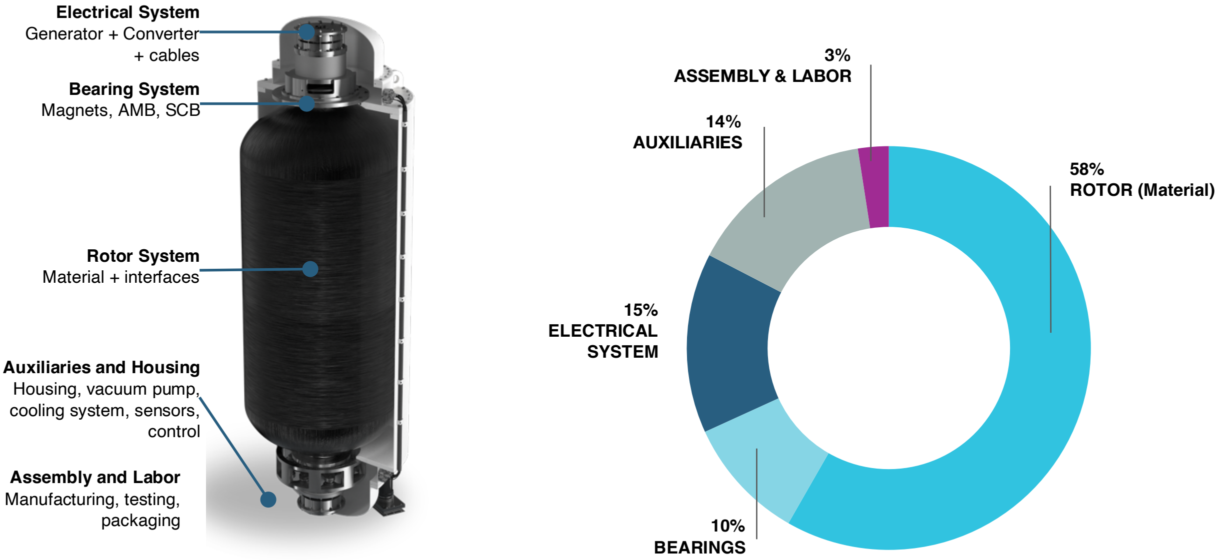


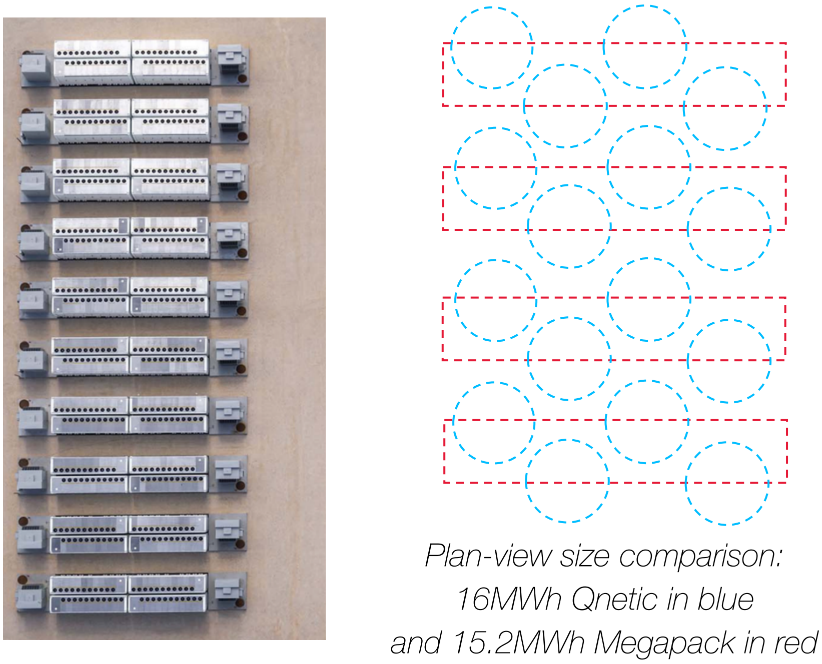
Figure 5: Qnetic equipment cost breakdown

Qnetic total equipment Capex target is 100$/kWh.
The electrical system takes 15% of that cost so 15$/kWh or 60$/kW for a 4h duration system. Our system cost is predominantly influenced by the rotor material, crafted from high-strength composites (carbon fiber and epoxy) using a manufacturing process like that of hydrogen tanks. With burgeoning demand from automotive, wind turbine, and hydrogen tank markets, there is a significant surge in production capacity for carbon fiber, leading to a substantial reduction in costs.

Note on Qnetic Capex:
We have developed a clear and achievable roadmap to reach our target price of $100 per kWh for the complete system. The details of this plan are not disclosed in this document. If you'd like to learn more, please contact the author directly.

4.2.2 Qnetic Installation cost.

In terms of installation, Qnetic has the same footprint as lithium-ion LFP systems. If we compare the Qnetic Q1000 (1000kWh kinetic battery) footprint with the Tesla Megapack, we have a very similar footprint (93kWh/m^2 for Qnetic vs 89kWh/m^2 for Tesla).



Plan-view size comparison:
16MWh Qnetic in blue
and 15.2MWh Megapack in red

Figure 6: Qnetic land footprint compared to lithium-ion.

In terms of electrical installation and grid connection, Li-ion LFP and Qnetic are very similar and could be swapped one with another with minor differences.

PNNL estimated the EPC (Engineering, Procurement, and Construction) cost for lithium-ion systems by including non-recurring engineering costs, construction equipment, shipping, siting, installation, and commissioning of the energy storage system (ESS). The cost is then weighted based on system duration.

While Qnetic has a comparable land footprint to lithium-ion, there are key differences that impact its installation cost:

- **Energy Density:** Qnetic's energy density is lower than that of lithium-ion LFP. Qnetic offers approximately 20 Wh/kg, compared to Lithium LFP's 102 Wh/kg for the full system. This results in higher transportation and lifting equipment costs for Qnetic.
- **Underground Installation:** Qnetic is designed for underground installation, which necessitates excavation and site-specific civil engineering, adding complexity and cost to the process.

Figure 7: Qnetic installation underground.

As a conservative figure, we estimated the excavation cost to be 18$/kWh and the EPC to be 25% more expensive than lithium-ion.

$$Qnetic\ EPC = Li\text{-}ion\ LFP\ EPC \times 1.25 + 18$$

This brings us to a total EPC cost for Qnetic of 103 $/kWh.

5 LCOS Results

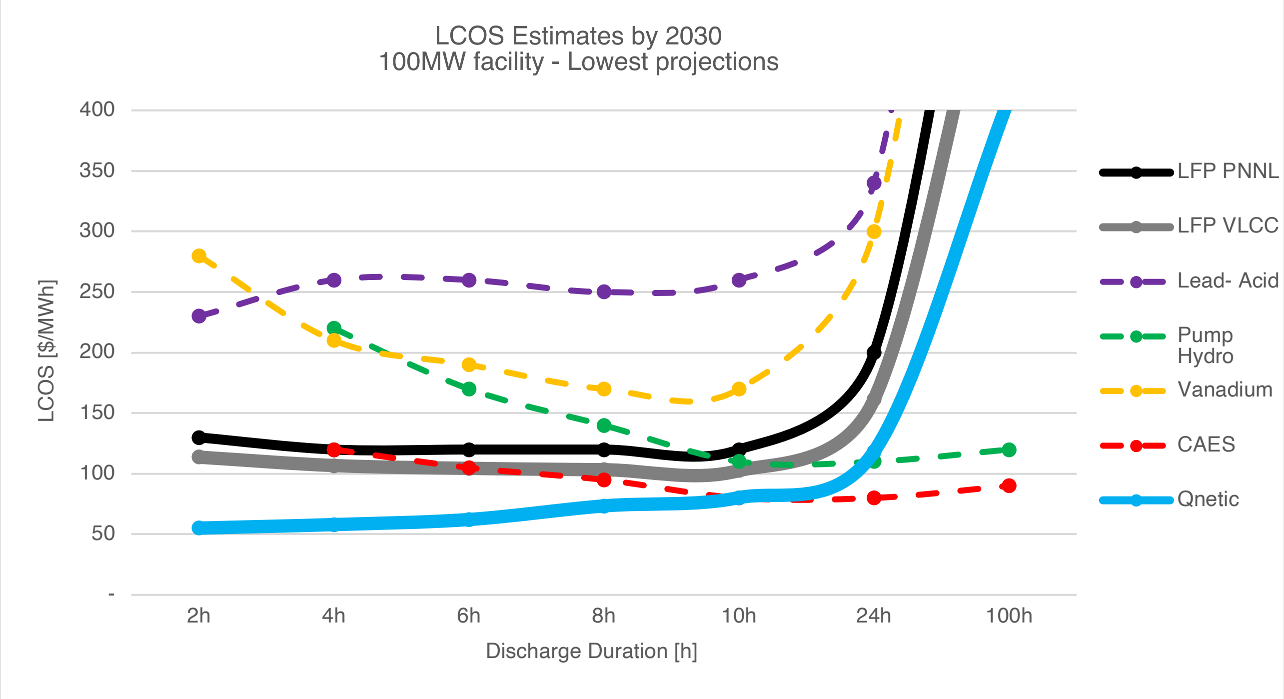


Figure 8: LCOS Comparison by 2030, 100MW project, lowest projections according to PNNL

***Source**: Qnetic Corporation for Qnetic LCOS ; https://www.pnnl.gov/projects/esgc-cost-performance/lcos-estimates for all other technologies.*

5.1 Making sense of those results

In the discharge duration range of 2 to 12 hours, Qnetic demonstrates the lowest Levelized Cost of Storage (LCOS) across various technologies.

Current market data indicates that a significant portion of the energy storage market is focused on medium-duration storage, specifically around 4 hours of discharge. Additionally, there is a smaller, yet growing segment dedicated to long-duration energy storage (LDES), which can discharge for significantly longer periods, exceeding 12 hours.

Focusing specifically on the 4-hour discharge duration, Qnetic's LCOS is half the cost of Lithium-ion LFP batteries Very Low Cell Cost, which is artificially tuned to have a very low storage block cost of $50 per kWh. **It is important to explain the reasons behind this significant cost difference.**

5.2 Capex and Efficiency Comparison

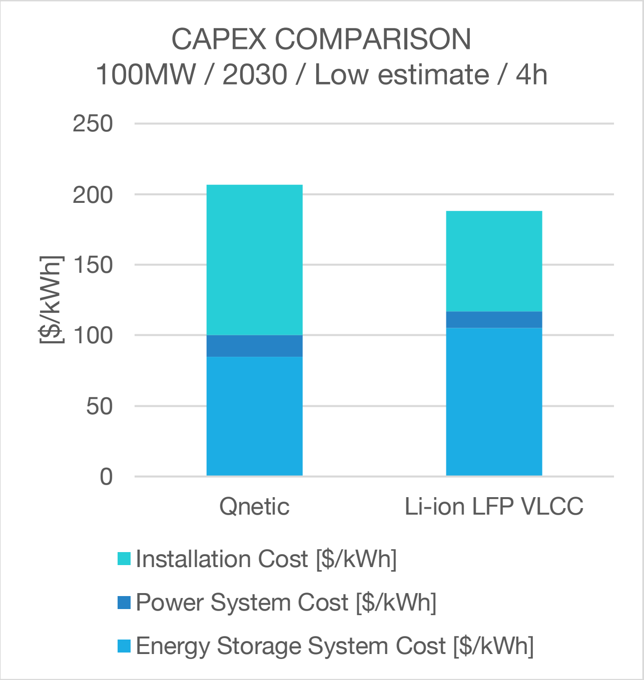


Figure 9: Capex comparaison, Qnetic vs Lithium-ion LFP VLCC

When comparing capital expenditures (Capex), we find that the fully installed cost of Lithium-ion LFP Very Low Cell Cost is 10% cheaper than that of Qnetic. In terms of efficiency, both Qnetic and Lithium-ion LFP Very Low Cell Cost have the same round-trip efficiency (RTE) of 85%.

Additionally, Qnetic experiences an average self-discharge rate of 2.26% per cycle, meaning 2.26% of the stored energy is lost during each cycle due to friction and heat.

So, how does Qnetic achieve a significantly lower Levelized Cost of Storage (LCOS) compared to Lithium-ion LFP batteries?

5.3 Degradation and cycle life

The degradation of a battery refers to the gradual loss of performance or capacity in a battery over time, especially with repeated charge-discharge cycles, which is a significant concern for lithium-ion batteries compared to flywheel energy storage, as flywheels experience minimal degradation due to their purely mechanical energy storage mechanism, making them last much longer with minimal maintenance.

The key differences between lithium-ion and flywheel energy storage regarding degradation are listed below:

Lithium-ion degradation:

- **Chemical reactions:** Lithium-ion batteries store energy through chemical reactions within their electrodes, which can degrade over time due to factors like high temperatures, deep discharge cycles, and the formation of unwanted compounds on the electrode surfaces.
- **Capacity loss:** As lithium-ion batteries degrade, their capacity to store energy decreases, meaning they can deliver less power per charge cycle.
- **Cycle life:** The number of charge-discharge cycles a lithium-ion battery can endure before significant degradation occurs is limited, depending on usage conditions.

Qnetic flywheel zero degradation:
Mechanical energy storage: Qnetic stores energy by spinning a rotor at high speeds in a vacuum with a contactless bearings, there is no wear of the system and no capacity loss over time.
Long lifespan: Due to the lack of significant chemical processes, flywheels have a much longer lifespan compared to lithium-ion batteries.

The Depth of Discharge is “The percentage of energy discharged from a storage system relative to the system’s total energy capacity.” (PNNL). According to data from PNNL, to limit the lithium-ion LFP battery degradation it is operated at two different Depth of Discharge (DOD). The first phase involves a Depth of Discharge (DOD) of 80%, from the first to the 5005th cycle, and the second consists of a DOD of 60%, from the 5006th cycle to the 9100th cycle—marking the battery’s End of Life.

In contrast, Qnetic’s energy storage system is designed for exceptional longevity, capable of cycling twice daily for 30 years (or approximately 22,000 cycles) before reaching its theoretical fatigue life.

At its theoretical End of Life, the rotor is expected to remain intact, and with proper inspection, it can likely continue operating safely for many additional years. Unlike chemical batteries, the composite material’s degradation in Qnetic’s rotor does not impact its capacity, ensuring consistent performance over time.

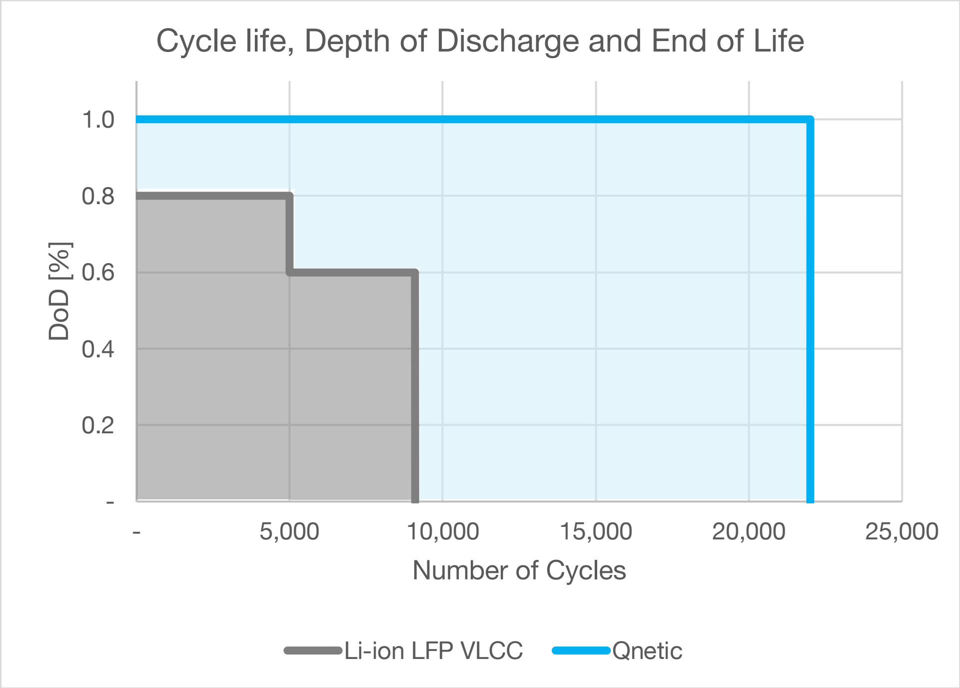


Figure 10: Cycle Life, Depth of Discharge, End of Life comparison: Qnetic vs Lithium-ion LFP VLCC

The figure above highlights one of the key differences between Qnetic and Lithium-ion LFP batteries.

As a result, Qnetic can trade 3.4 times more energy compared to lithium-ion LFP batteries. This translates into the potential for Qnetic to generate up to three times more revenue than its lithium-ion LFP counterpart.

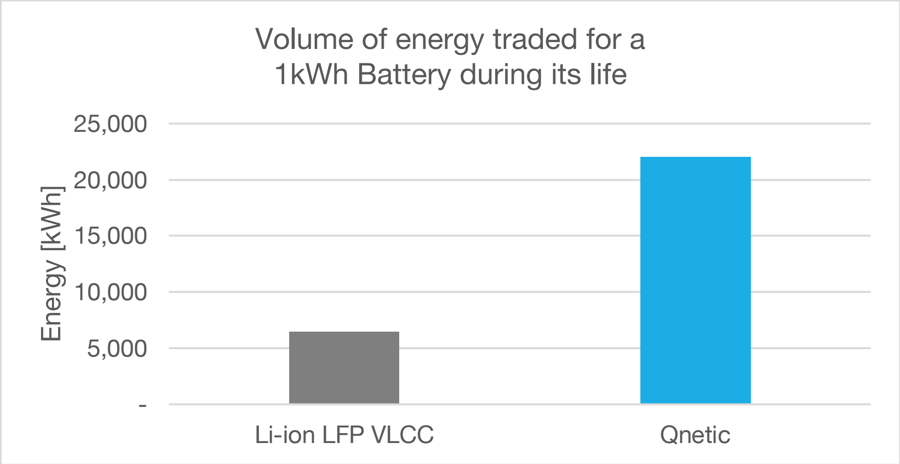


Figure 11: Volume of energy traded for a 1kWh Battery during its life

5.4 Impact of daily multi-cycling

Grid-scale lithium-ion batteries are typically limited to a single discharge cycle per day by OEM warranties due to the significant degradation caused by charging and discharging. The more cycles a lithium-ion battery undergoes, the shorter its lifetime.

Qnetic, does not suffer from these drawbacks. Its lifespan is unaffected by multi-cycling, and its highly responsive nature, combined with an exceptionally high cycle count, makes it an ideal solution for multiple charge-discharge cycles per day whenever feasible.

The calculated Levelized Cost of Storage (LCOS) in the table below incorporates these considerations.

Annual Cycles	**2h duration**	**4h duration**	**6h duration**	**8h duration**	**10h duration**	**24h duration**	**100h duration**
Li-ion LFP VLCC	300	300	300	300	250	130	28
Qnetic	1,000	600	450	300	250	130	28

5.5 Limitations

It is important to distinguish between LCOS and revenue.

To calculate the revenue of an energy storage system, you need to determine the amount of energy it discharges multiplied by the price per kWh it can sell at during peak demand periods, taking into account factors like charging times, discharge efficiency, and market price fluctuations; while LCOS (Levelized Cost of Storage) represents the average price per kWh the system needs to sell its energy at over its lifetime to break even on all costs associated with building and operating it, essentially acting as a benchmark for economic viability.

6 Conclusions

The Qnetic kinetic energy storage system represents a transformative solution, addressing the critical need for storage duration between 4 to 12 hours, with a cost-efficient mechanical battery to support the global transition to renewable energy. Through innovative design and the use of advanced materials, Qnetic delivers the lowest Levelized Cost of Storage (LCOS) for medium to long discharge durations (4–12 hours), significantly outperforming competing technologies such as lithium-ion batteries, pumped hydro, and compressed air energy storage. Even when considering very low cell cost for Lithium-ion LFP Qnetic manages to be half the cost of LFP for a four-hour discharge duration storage.

Qnetic achieves a highly competitive LCOS of approximately $55–80/MWh for discharge durations from 2 up to 12 hours, making it the most economical solution for grid-scale storage. The key advantages of Qnetic are:

- Zero Degradation: Unlike conventional battery technologies, Qnetic's system experiences no capacity fade over its multi-decade operational lifespan, ensuring reliability and cost savings.
- High Round-Trip Efficiency: With a grid-to-grid efficiency of 85%, energy losses are minimized, further enhancing the system's economic viability.
- High Cycle life: With its capacity to cycle multiple times a day it significantly outperforms lithium-ion in the duration range of 2 to 8h.

By delivering superior performance and economic advantages, Qnetic is uniquely poised to revolutionize the energy storage landscape, enabling the integration of renewable energy into a stable, resilient grid. For stakeholders, investors, and energy providers seeking to align with global climate goals, Qnetic offers a future-proof solution to meet evolving energy demands efficiently and sustainably.

END.