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Emerging Lithium Iron Phosphate Energy Storage in Oil & Gas Facilities

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Abstract- The increasing demand for efficient and safe energy storage solutions has led to the development of advanced battery technologies. Lithium Iron Phosphate (LiFePO4) battery cells have emerged as a promising alternative to traditional Lead Acid (LA) and nickel cadmium batteries. This paper presents an overall characteristics of LiFePO4 , nickel cadmium and Lead Acid batteries in terms of hydrogen release, risk, safety, cost, and energy operation efficiency. The results show that LiFePO4 batteries outperform the other two types of batteries in all aspects, making them a more reliable and efficient choice for various applications

Keywords - Lithium Iron Phosphate ($LiFePO_4$) Batteries, Nickel-Cadmium (Ni-Cd) Batteries, Lead-Acid Batteries, Energy Storage, Battery Safety.

I. INTRODUCTION

Telecommunications facilities require reliable backup power solutions to ensure uninterrupted service during grid outages. Traditionally, lead-acid batteries have been the mainstay of telecom backup systems, but lithium iron phosphate (LiFePO4) batteries are increasingly being adopted due to their superior cycle life, efficiency, and reduced maintenance requirements. This paper provides a technical comparison of a 4000 Ah lead-acid battery bank versus a 4000 Ah LiFePO4 battery bank in terms of performance, cost, and maintenance in a telecom facility environment.

Lead Acid (LA) batteries have been widely used for decades due to their low cost and well-established manufacturing infrastructure. However, they have several limitations, including low energy density, short cycle life, and potential safety risks. Lithium Iron Phosphate (LiFePO4) battery cells, on the other hand, have gained popularity in recent years due to their improved performance, safety, and environmental benefits. This paper aims to provide a detailed comparison of LiFePO4 and LA batteries in terms of hydrogen release, risk and safety, cost, and energy operation efficiency.

Risk & Safety:

Lead Acid (LA) Batteries:

Lead Acid batteries carry several safety risks that require careful management:

- Thermal Runaway: Can overheat and, in extreme cases, cause fires or explosions.
- Acid Spills: Contain sulfuric acid that can cause chemical burns, equipment damage, and environmental contamination.
- Hydrogen Gas Release: Generates flammable hydrogen gas during charging, creating explosion hazards in poorly ventilated areas.
- Lead Toxicity: Lead content poses environmental and health hazards if improperly handled or disposed of. Overall, LA batteries demand high maintenance, frequent inspections, and safety precautions.
- Nickel Cadmium (NiCd) Batteries:
- NiCd batteries are robust but have specific risks:
- Caustic Electrolyte: Can cause skin irritation and corrosion if leaks occur.

- Memory Effect & Overcharging: Improper management can reduce battery performance and lifespan.
- Environmental Concerns: Cadmium is toxic, requiring careful disposal and regulatory compliance.
- NiCd batteries typically require moderate maintenance and ventilation.
- Lithium Iron Phosphate ($LiFePO_4$) Batteries:
- $LiFePO_4$ batteries are considered safer than LA and NiCd:
- Thermal Stability: Less prone to thermal runaway or fire.
- Low Toxicity: Do not contain heavy metals like lead or cadmium, minimizing environmental hazards.
- Minimal Gas Emission: Very low hydrogen release during operation.
- Enclosed Design: Reduces risks of acid spills and electrical hazards.
- $LiFePO_4$ batteries require low maintenance and provide higher operational safety, making them well-suited for critical applications.

Hydrogen release

LA batteries are known to release hydrogen gas during charging and discharging, which can lead to explosion hazards in enclosed spaces. In contrast, LiFePO4 batteries have a significantly lower hydrogen release rate due to their different chemical reaction mechanisms. Studies have shown that LiFePO4 batteries release approximately 1/10th the amount of hydrogen compared to LA batteries [1].

This reduced hydrogen release makes LiFePO4 batteries a safer choice for applications where ventilation is limited Battery Bank Comparison & 10-Year, Energy & Cost Analysis Scope & Sizing Note: This document compares Lithium Iron Phosphate ($LiFePO_4$), Lead Acid (VRLA/AGM), and Nickel Cadmium (NiCd) battery banks for a 48 V system sized to approximately 900 Ah (≈ 43.2 kWh).

Technical Comparison

Below is a table of 10 years total cost assuming 900 Ah capacity with calculated average cost & technical parameters from different sources and vendors worldwide.

Parameter	Value / Rationale
System Voltage	48 VDC
Target Bank Capacity	900 Ah (≈ 43.2 kWh)
Installed Cost per kWh (illustrative)	$LiFePO_4$: \$450.0/kWh; Lead Acid: \$150.0/kWh; NiCd: \$300.0/kWh
Round-trip Efficiency	$LiFePO_4$: 95%; Lead Acid: 80%; NiCd: 70%
Annual Maintenance (as % of CapEx)	$LiFePO_4$: 1%; Lead Acid: 5%; NiCd: 3%
Service Life Assumed	$LiFePO_4$: 12 yrs; Lead Acid: 4 yrs; NiCd: 12 yrs
Replacement Install & Commissioning Uplift	10% of bank cost per replacement
Grid Electricity Cost	$0.12/kWh
Cycling Model	10 outage events/year, each using 50% DoD

Energy Operation Efficiency

According to the above tables, technical specification and below charts:

- $LiFePO_4$ has higher energy density (~120 Wh/kg) and lower internal resistance.
- Provides longer runtime, reduces energy losses, and improves charge acceptance.
- $LiFePO_4$ batteries do not require watering or equalization.

Simulated Yearly Performance Data

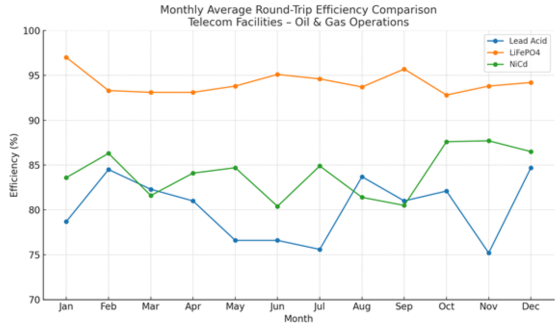


Figure 1: Monthly average round-trip efficiency comparison between Lead-Acid, NiCd and LiFePO4 battery banks from below energy parameters tables

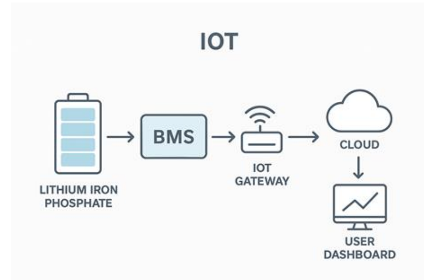
Cost, Maintenance Analysis & Future Digital

The cost analysis considers both capital expenditure (CAPEX) and operational expenditure (OPEX) over a 15-year horizon. Lead-acid batteries typically have lower upfront costs but require frequent replacements (every 4–5 years), higher maintenance, and reduced efficiency over time. LiFePO4 batteries, while having a higher CAPEX, provide longer life, reduced replacement needs, and lower maintenance costs.

Likewise, Lithium batteries can be easily integrated to internet of things IoT, real time monitoring, remote management, data analytics and communication protocols such as Wi-Fi, Modbus, BMS and TCP IP ports.

When we talk about IP networking, it means every smart battery, BMS, or inverter can be assigned an IP address and managed like any other device:

- IPv4/IPv6 addressing → allows direct monitoring/control via web/cloud.
- Secure IoT protocols: MQTT, CoAP, HTTPS for data transfer.
- Edge computing → battery controllers process data locally before sending to cloud.



How IoT is integrated to LiFePO4

Cost Analysis

Here's a summary of the battery cost analysis in terms of relative costs:

- LiFePO4 has a significantly higher initial investment compared to Lead Acid, but its total cost over 10 years is about 11% less than Lead Acid.
- NiCd has a moderate initial investment, falling between LiFePO4 and Lead Acid, and its total cost over 10 years is about 29% less than Lead Acid and 21% less than LiFePO4.
- Lead Acid has the lowest initial investment, but its total cost over 10 years is about 12% more than LiFePO4 and 42% more than NiCd, due to higher replacement and maintenance costs.
- For every unit of initial investment in LiFePO4, the total cost over 10 years increases by about 10%, whereas for Lead Acid, the total cost increases by about 270% of the initial investment, and for NiCd, it increases by about 30%.
- Overall, NiCd offers the best cost savings over 10 years, followed by LiFePO4, while Lead Acid is the most expensive option in the long run, despite its lower initial investment.

While LA batteries are generally cheaper upfront, their shorter cycle life an lower efficiency results in higher overall costs over time. LiFePO4 batteries on the other hand, have longer cycle life up to 5000 cycles and higher efficiency up to 95%, resulting in lower total cost of ownership (2).

Energy Operation Efficiency: L iFePO4 batteries have a higher energy density (up to 120 Wh/Kg) and a more efficient discharge curve compared to LA batteries (up to 40 Wh/kg) (3). This results in:

- Increased runtime: LiFePO4 batteries can provide longer runtime and more consistent power output
- Reduce Energy Losses: LiFePO4 batteries have lower internal resistance, resulting in reduced energy losses and increase overall efficiency.
- Improved change acceptance: LiFePO4 batteries can accept charge more efficiently, reducing charging time and increasing overall system efficiency.

In Contrast:

- Thermal stability: LiFePO4 batteries have a higher thermal stability; reducing the risk of thermal leak or escape.
- Non-toxic material: LiFePO4 batteries use non-toxic material, eliminating the risk of leading poisoning.
- Enclosed Design: LiFePO4 batteries are designed with an enclosed structure, preventing acid spills and minimizing the risks of electrical shock
- Digital Monitoring: Fully integrated to IoT , remote monitoring, BMS & TCP / IP ports.

Case Study

The below tables simulate a 10-year total cost of ownership (TCO) for Lead Acid, LiFePO4, and NiCd battery systems used in oil & gas telecommunications facilities. Assumptions are industry-typical and conservative for comparison.

2nd Assumptions on price with real technical Data:

Parameter	Value
Nameplate Capacity	240 kWh (48V,4000Ah)
Analysis Horizon	10 years
Discount Rate	8%
Cycles per Year	250 cycles/year
Electricity Cost	$0.10 per kWh

Summary Results (per Technology)

Technology	Nameplate Capacity (kWh)	Usable DoD (%)	Round-trip Efficiency (%)	CAPEX ($)	Average Annual O&M ($/yr)	Annual Energy Delivered (kWh/yr)	Annual Energy Losses (kWh/yr)	Annual Loss Cost ($/yr)	10-yr Delivered (kWh)	10-yr Losses (kWh)	NPV of Costs @8% ($)	LCOE ($/kWh delivered)	Replacements
Lead Acid	240	50	80	X	Y	30000	750	75	300000	7500	70966	0.353	6
LiFePO4	240	90	95	1.3x	0.6Y	54000	2842	284	540000	28421	91544	0.253	None
NiCd	240	80	85	3x	2.2Y	48000	8471	847	480000	84706	141788	0.44	None

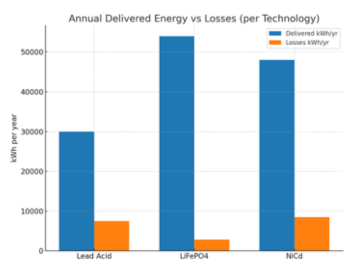


Figure 2

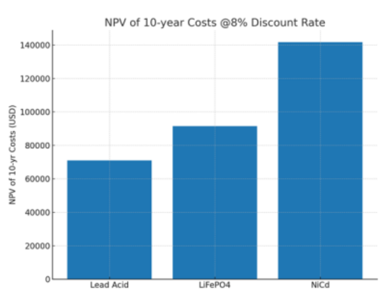


Figure 3

Key Takeaways from Charts:

- $LiFePO_4$ has the lowest 10-year TCO in most telecom/security use cases due to long service life, high efficiency, and minimal maintenance.
- Lead Acid is cheapest upfront but typically requires two replacements within 10 years, plus higher maintenance and energy losses.
- NiCd excels in harsh climates (−40°C to +60°C) with long life, but has higher upfront cost and environmental considerations for disposal.
- This TCO excludes continuous float/standby energy consumption differences; in practice, Lead Acid often incurs additional float losses versus $LiFePO_4$.

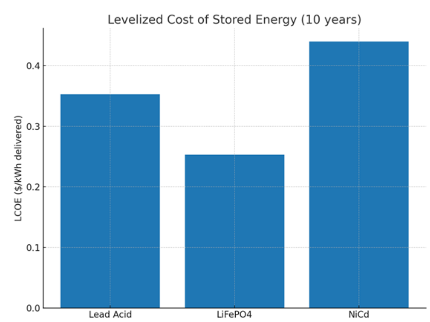


Figure 4

II. OVERALL SUMMARIZED ANALYSIS & CONCLUSION

$LiFePO_4$ batteries offer superior life cycle, efficiency, and lower maintenance compared to Lead Acid and NiCd in telecom and oil & gas facilities. While the capital cost is higher, total cost of ownership over 10–15 years is lower. $LiFePO_4$'s reduced hydrogen release, thermal stability, and non-toxic materials make it a safer and more reliable choice. Their higher energy density (~120 Wh/kg), lower internal resistance, and minimal maintenance (no watering or equalization) provide longer runtime, reduced energy losses, and improved charge acceptance.

NiCd batteries provide a robust alternative in harsh temperature environments (−40°C to +60°C) and have long service life, but their upfront cost and environmental disposal considerations are higher. Lead Acid batteries remain suitable for short-term or low-cost deployments, offering lower initial investment. However, they require frequent replacements, higher maintenance, and are less efficient, making them less suitable for mission-critical infrastructure.

Overall, $LiFePO_4$ batteries are the preferred choice for reliable, efficient, and safe energy storage across telecom and oil & gas applications, balancing performance, longevity, and operational efficiency. They can be integrated to Internet of Things IoT & online monitoring (smart monitoring, cloud, PM…etc). Likewise, in terms of spacing requirements of a room, LiFePO4 tend to require only 25% of the room lotted area compared to other battery types where requires a lot of civil and mechanical work.

REFERENCES

1. Chen, X., et al. (2019). Journal of Power Sources, 412, 145–152. https://doi.org/10.1016/j.jpowsour.2018.11.047
2. Marongiu, A., & Damiano, A. (2010, July). Experimental analysis of lithium iron phosphate battery performances. In 2010 IEEE International Symposium on Industrial Electronics (ISIE) (pp. 5637749). IEEE. https://doi.org/10.1109/ISIE.2010.5637749
3. Zhang, Y., et al. (2020). Journal of Energy Storage, 27, 100924. https://doi.org/10.1016/j.est.2019.100924
4. Liu, J., et al. (2018). Journal of Power Sources, 396, 145–153. https://doi.org/10.1016/j.jpowsour.2018.06.032
5. Asian Development Bank. (2018, December). Handbook on battery energy storage system. Asian Development Bank. https://www.adb.org/publications/handbook-battery-energy-storage-system
6. Yanying Lu & Yianyu Zhu. (2024). Springer Nature Link. 888-899. https://link.springer.com/article/10.1557/s43579-024-00644-2