Lithium Battery Application in Data Centers

Data Center Facility White Paper 101

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Foreword

Lithium-metal batteries and lithium-ion batteries are both categorized as lithium batteries. However, the term lithium batteries generally refers to lithium-ion batteries, which contain no metallic lithium and support cyclic charge and discharge.

In 1991, SONY launched its first commercial lithium-ion battery. In 2009, Huawei began large-scale use of lithium batteries in communications base stations. Since 2016, the electric vehicle market, which uses lithium batteries, has been growing exponentially. To date, the power output of power batteries sold by the world's top ten lithium battery manufacturers is equivalent to 90 GWh.

As the energy density and safety performance of lithium-ion batteries continues to improve — and as the cost declines — demand for lithium-ion batteries is increasing, across communications, electric power, electric vehicle, and data center fields. They are becoming a next-generation, mainstream source of energy.

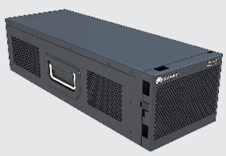
1. Why Are Lithium Batteries Needed?

Lead-acid batteries have dominated the communications industry for decades. But, due to disadvantages such as a short cycle life, large size, heavy weight, and environmental pollution in the production process, the development of lead-acid batteries is shrinking in several countries. Indeed, telecoms giant China Tower has even decided to halt bids for lead-acid batteries.

Lithium batteries offer several advantages, such as high energy density, a small footprint, and a long cycle life. As the market share of lead-acid batteries decreases rapidly, lithium battery usage is increasing around the globe. Lithium batteries are used in almost all 5G sites, alongside their wide use in the data centers of some large ISPs outside China. The market share of lithium batteries is predicted to approach or exceed that of lead-acid batteries in the next 3–5 years. It is widely agreed that lithium batteries will dominate the market in the future.

1.1 Basic Concepts

Lithium battery cabinet



Lithium battery module

Lithium battery cell

Basic Parameters

Battery capacity (Ah): The amount (typically measured in amp hour) of electric charge a battery can deliver at certain conditions (such as discharge rate, temperature, and end-of-discharge voltage).
Charge or discharge rate (C): Charge or discharge current divided by rated capacity.

Working Principle

Typically, a lithium-ion battery uses lithium alloy metal oxide as the cathode material, graphite as the anode material, and contains non-aqueous electrolytes.

Cathode material: There are many optional cathode materials. The mainstream products are lithium iron phosphate (LFP), nickel cobalt manganese (NCM) or nickel cobalt aluminum (NCA).
Anode material: Graphite is predominantly used.

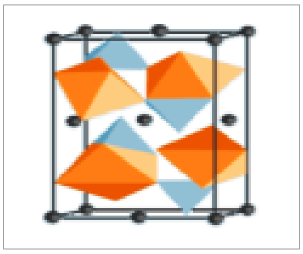
LFP battery example:
Cathode reaction: Lithium-ions are embedded during discharge and deintercalated during charge.
Charge: LiFePO4 → Li1-xFePO4 + xLi+ + xe-
Discharge: Li1-xFePO4 + xLi+ + xe- → LiFePO4

Anode reaction: Lithium-ions are deintercalated during discharge and embedded during charge.
Charge: xLi+ + xe- + 6 C → LixC6
Discharge: LixC6 → xLi+ + xe- + 6 C

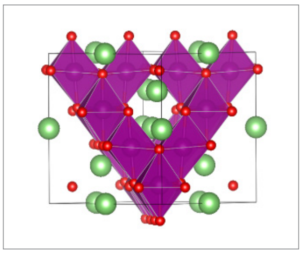
Battery Classification (by Cathode Material)

$LiCoO_2$ (LCO)
$LiMnO_2$ (LMO)
$LiFePO_4$ (LFP)
$LiNiCoMnO_2$ (NCM)

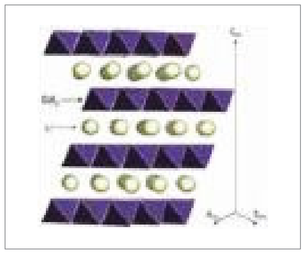
Cathode Material Structure



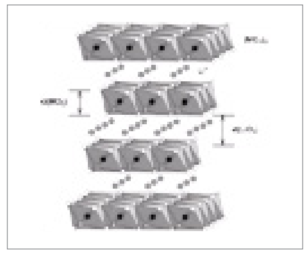
LFP
Olivine three-dimensional structure
More stable



LMO
Cubic crystal structure
Stable



LCO
Layered two-dimensional structure
Variable



NCM
Layered two-dimensional structure
Variable

1.2 Long Cycle Life

Lithium batteries feature a long cycle life, long float charging life, high discharge efficiency, low capacity loss in fast discharge, high energy density, and a small footprint. They are advantageous in scenarios with limited space. As lithium battery costs continue to decline, they will be increasingly deployed in data centers.

Lithium batteries have a far longer cycle life than lead-acid batteries.

Lithium battery:

- 100% Depth Of Discharge (DOD): up to 3000 cycles; deep discharge: at least 3000 cycles
- 50% DOD: up to 6000 cycles; shallow discharge: at least 6000 cycles

Lead-acid battery:

- 100% DOD: approximately 150 cycles; deep discharge: requires frequent replacement in poor power grid scenarios
- 50% DOD: approximately 600 cycles; shallow discharge: requires frequent replacement in poor power grid scenarios

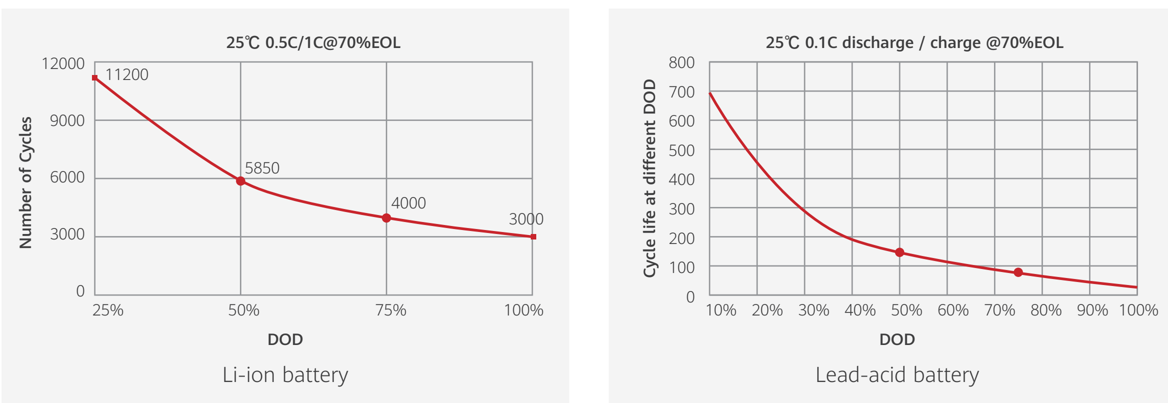


Figure 1: Cycle life curves of lithium and lead-acid batteries

1.3 Long Float Charging Life

The float charging life of lithium batteries is more than twice that of lead-acid batteries.

Lithium battery:

- 70% End-Of-Life (EOL) float charging at 25℃ : up to 15 years; no need for replacement within the 15 year life cycle if the power grid is adequate

Lead-acid battery:

- 70% EOL float charging at 25℃ : up to 7 years; requires replacement every 3–7 years even if the power grid is adequate; labor-intensive and high battery cost

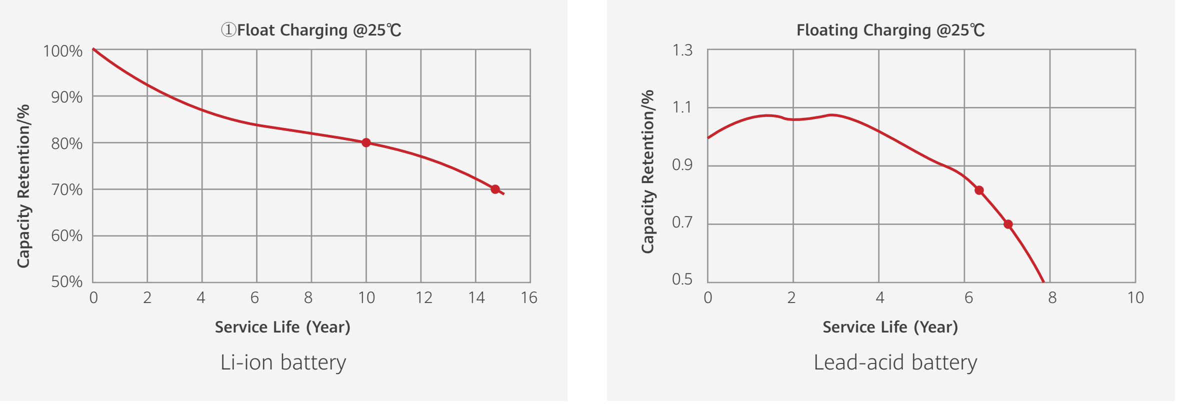


Figure 2: Float charging life curves of lithium and lead-acid batteries

1.4 High Discharge Efficiency, Low Capacity Loss in Fast Discharge

Lithium batteries are suitable for data centers that require the discharge of energy at a high rate, in a short time span.

Lithium battery:

- Short-time discharge at a high rate: more energy is discharged. As the discharge rate increases, discharge capacity remains stable and can exceed 90%.

Lead-acid battery:

- Short-time discharge at a high rate: less energy is discharged. As the discharge rate increases, discharge capacity decreases rapidly. More batteries are needed to offset the disadvantage, which increases battery investment.

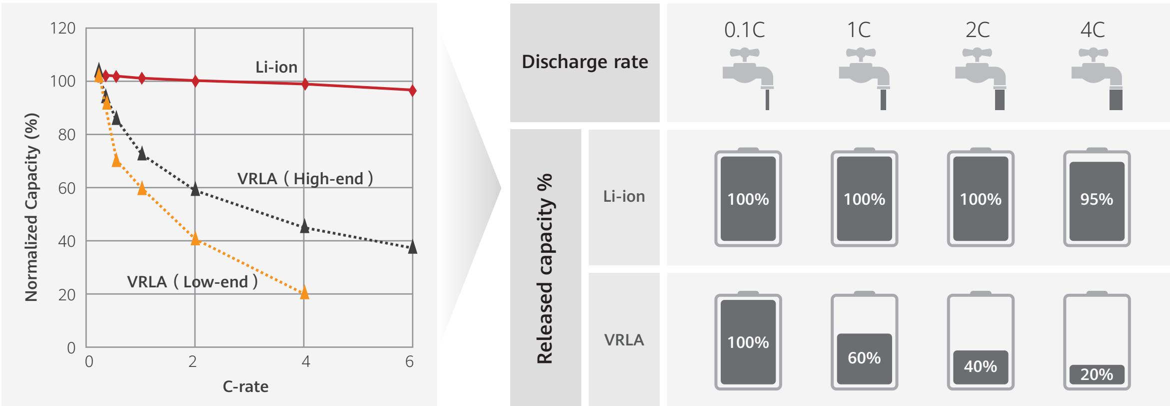


Figure 3: Discharge curves of lithium and lead-acid batteries at different rates

1.5 High Energy Density, Small Footprint

Lithium batteries are approximately 70% lighter and smaller than lead-acid batteries. They are preferred in scenarios with limited space.

Weight/energy density (Wh/kg) ratio: 3:1

- Lithium battery: 100–150; lead-acid battery: 30–50

Volume/energy density (Wh/L) ratio: 3:1

- Lithium battery: 200–300; lead-acid battery: 60–90

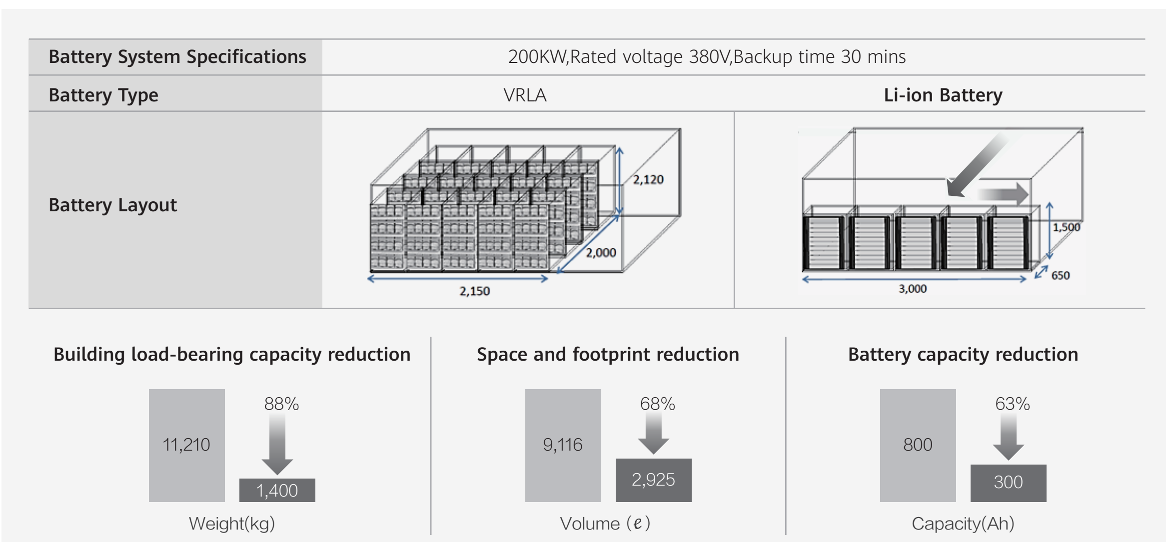


Figure 4: Footprint and weight comparison between lithium and lead-acid batteries for the same backup time

2. Why Are LFP Batteries Needed?

Currently, mainstream lithium batteries in the industry include LCO, LMO, LFP, and NCM batteries. LCO batteries are mainly applied in the mobile phone industry. LMO batteries are mainly used in the electric bicycle industry. LFP batteries are widely used in buses and energy storage plants, while NCM batteries are widely used in household vehicles, taxis, and energy storage plants. LFP and NCP batteries are commonly used in data centers. LFP batteries are more reliable, while NCM batteries provide higher energy density.

2.1 Stable Structure

LFP batteries feature high thermal stability as well as a low rate and amount of heat yield.

- LFP batteries are stable and generate little heat in high temperature environments. The peak power output for heat yield is only approximately 1 W.
- NCM batteries are prone to oxygen evolution at high temperatures or pressure, which increases the burning possibility. The peak power rate for heat yield is approximately 80 W/min. Explosive burning (within seconds) can easily be triggered, which is hard to control.
- The total heat generated by LFP batteries is far lower than that of NCM and LMO batteries (the area formed by the heat yield power curve and the horizontal axis represents the total heat generated).

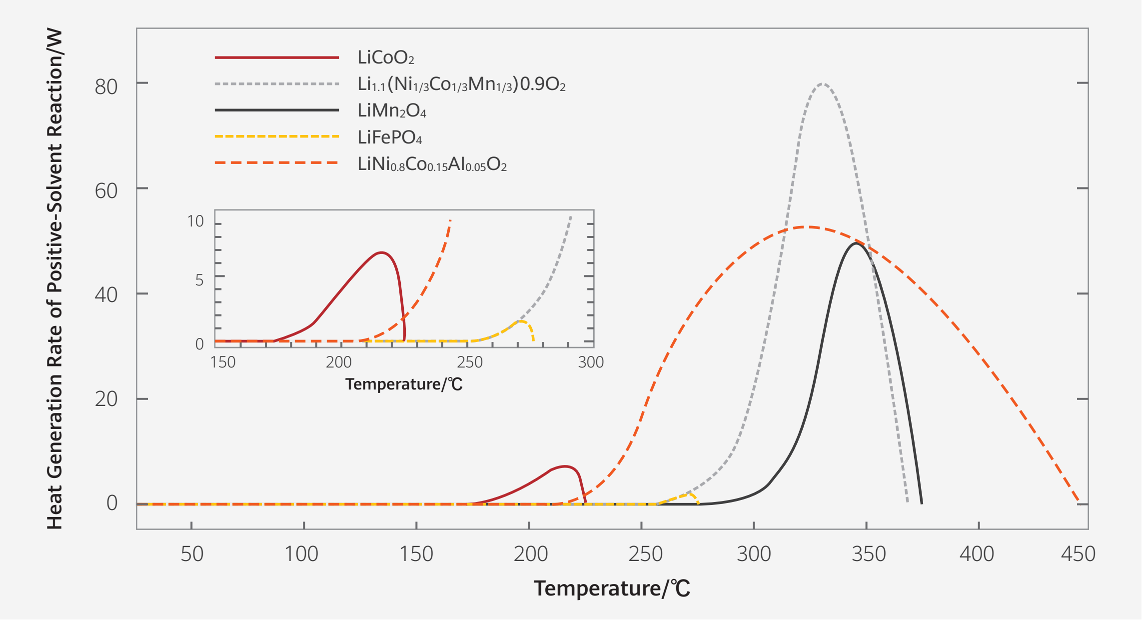
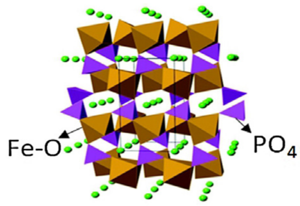


Figure 5: Heat generated by lithium batteries at different high temperatures

Source： P. Peng, F. Jiang., Thermal safety of lithium-ion batteries with various cathode materials: A numerical study. **International Journal of Heat and Mass Transfer**. 103 (2016) 1008–1016

LFP batteries do not release oxygen in case of overcharge and overdischarge.

LFP batteries use an olivine three-dimensional structure, which is more stable and does not release the oxygen due to thermal runaway.

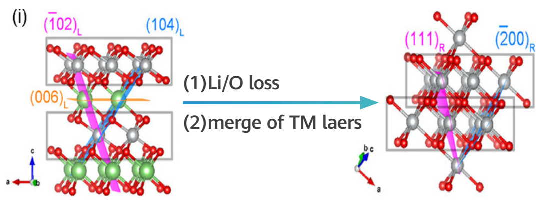


No combustible substance or oxygen element released, stable structure

Slow heat yield, no risk of fire or explosion

NCM batteries release oxygen in case of overcharge and overdischarge.

NCM batteries use a layered two-dimensional structure, which is easy to deform and release oxygen due to thermal runaway.



Structure breakdown, oxygen released

Sharp rise in temperature, fire and explosion

Source: Soroosh Sharifi-Asl, et al., Oxygen Release Degradation in Li-Ion Battery Cathode Materials: Mechanisms and Mitigating Approaches. **Adv. Energy Mater.** 2019, 1900551.

2.2 Stable Performance

Test conclusion: LFP batteries are more reliable than NCM batteries.

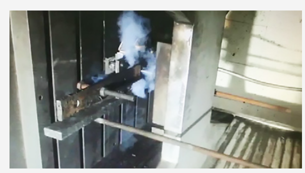
Common test method:

- Puncture the cell with a needle to check its stability in the case of an internal short circuit.
- Secure the fully charged battery.
- Use an 8 mm diameter high-temperature-resistant steel needle to puncture through the geometrical center of the cell in the direction vertical to the cell polarity plate at a speed of 25 mm/s, keep the needle in the cell, and observe for 1 hour.

Test conclusion:

- After an LFP battery is punctured with a needle (internal short circuit), the heat of reaction inside the cell is minimal. The highest surface temperature of the cell is only 80° C, the cell does not catch fire or leak electrolytes, and its shell is intact.
- After an NCM battery is punctured with a needle (internal short circuit), the cell reacts violently internally and generates a large amount of heat and oxygen in a short time. The battery burns within one second, thermal runaway occurs within four seconds, the highest surface temperature reaches 458° C, and the shell melts.

No fire of LiFePO4 nail test



Fire of NCM nail test

Table 1: Safety test comparison between LFP and NCM batteries (puncture test)

Material	Composition	Highest Temperature	Puncture Test Result
NCM battery	$Li(NiCoMn)_{1/3}O_2$	458℃	Burning within 1 second, thermal runaway within 4 seconds, and shell melting
LFP battery	$LiFePO_4$	80℃	No electrolyte leakage, intact shell, no burning

Figure 6: Safety test comparison between LFP and NCM batteries (puncture test)

Source： K.Zaghib, et al., Enhanced thermal safety and high power performance of carbon-coated LiFePO4 olivine cathode for Li-ion batteries. **Journal of Power Sources**, 219, 2012: 36-44

3. Summary of Data Center Lithium Battery Application

Table 2: Battery recommendations for data centers

Item	Lead-Acid Battery	NCM Battery	LFP Battery	Recommend	Reason
Footprint	Large	Smallest	Small	Lithium battery	Space saving
Cycle life	Short	Long	Long		A solution in poor power grid scenarios
Float charging life	Short	Long	Long		No need to replace within the life cycle
Discharge rate	Low	High	High		Short-time high-current discharge in data centers
Discharge efficiency	Low	High	High		Large energy for short-time discharge
Chemical stability	Poor	High Layered two-dimensional structure	Highest Olivine three-dimensional structure	Lithium Battery-LFP battery	High reliability
Puncture test	N/A	Fire	No fire		High reliability

Note: NCM batteries have a higher energy density but lower reliability than LFP batteries. LFP batteries are recommended for data centers to keep balance between reliability and energy density.

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