Beyond Lithium-Ion: The Promise and Pitfalls of BYD's Blade Batteries for Electric Vehicles

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Abstract. Electric vehicles with batteries have started to create a significant impact on the automobile industry nowadays. Along with battery manufacturers, automakers are developing new battery designs for electric vehicles, paying close attention to details like energy storage effectiveness, construction qualities, safety, affordability, and battery performance. The Chinese automaker developed the BYD Blade Battery Build Your Dream (BYD) in 2020. It is primarily a lithium iron phosphate (LFP) battery with prism-shaped cells, with an energy density of 165 Wh/kg and an energy density pack of 140Wh/kg. This essay briefly reviews the BYD Blade Battery's performance compared to other battery models, model architecture, safety implications of the nail penetration experiment, and cost comparisons with other alternatives.

1 Introduction

The electric vehicle industry is rapidly expanding, and one of the significant challenges is the development of a reliable and safe battery that can provide a long driving range. The traditional lithium-ion batteries used in electric vehicles have limitations such as low energy density, poor thermal stability, and a tendency to catch fire [1]. Modern vehicle manufacturing and battery manufacturing companies are developing new batteries to address these issues and solve them for safe uses in electric vehicles [2, 3]. The electric vehicle industry has been rapidly growing in recent years, with an increasing number of consumers choosing electric vehicles over traditional gasoline-powered cars [4–6]. However, one of the significant challenges for this industry is the development of a reliable and safe battery that can provide a long driving range [7, 8]. Lithium-ion batteries have been the primary choice for electric vehicle manufacturers, but they have some limitations, such as low energy density, poor thermal stability, and a tendency to catch fire [9–11]. In response to these limitations, Chinese battery manufacturer BYD has developed a new type of lithium-ion battery called

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the Blade Battery. The Blade Battery is a revolutionary new technology that addresses traditional lithium-ion batteries' shortcomings, offering a longer lifespan, higher energy density, and improved safety[12–14]. The Blade Battery has already made waves in the electric vehicle industry, and many experts believe it has the potential to become a game-changer in electric vehicle batteries[15]. In this short review, the paper provides an in-depth analysis of the Blade Battery, including its design, performance, costs, and safety features. Also, it discusses its potential implications for the future of electric vehicles.

The paper discussed the historical background and the research trends of electric vehicle battery technology in section 2; in section 3, the paper gave an overview of the BYD Blade Battery with its performance, design technology, safety, and the cost for users. This paper suggests future research in section 4 and concludes in section 5.

2 Related works

The cell chemistry underwent several iterations of optimization after the first LIB, which had capacities of around 80 Whk^{-1} and 200 WhL^{-1}, was marketed by SONY in 1991. The energy density was increased to 400 WhL^{-1} at a voltage of 4.2 V even though the first cells were based on a petroleum coke anode and a $LiCoO_2$ cathode. This was made possible by including EC as a co-solvent in 1991. In 1993 [16], Guyomard and Tarascon released a novel electrolyte formulation that contained $LiPF_6$ in an EC/DMC blend. This electrolyte is still the most used one today since it allowed for a significantly higher energy density of 250 $Whkg^{-1}$ and 600 WhL^{-1}.

The electrolyte and the graphite anode have mostly stayed the same, except for additions for performance stability. But there was always active development going on at the cathode. With a greater volumetric energy density of 600 WhL^{-1}, the co-oxide-based cathode is still one of the finest options for making tiny devices like smartphones and laptops. However, other elements also come into play for more prominent applications, and it quickly became apparent that using cobalt has significant drawbacks [17, 18]. The original cathode was scrutinized because Co is a costly, poisonous, and potentially dangerous raw element.

As a result of Co oxide's instability in structure in the over-delighted state, its chemistry has been deemed unsuitable for automotive applications. Additionally, oxygen is emitted at extreme temperatures of about 200°C, which can oxidize flammable components in the battery, including the organic material that makes up the electrolyte. Strongly exothermic, self-sustaining, and causing a thermal overload of the batteries, fires, or even explosions, this reaction has the potential to become self-sustaining [19].

Since then, several methods have been used to lower the Co concentration in battery materials to find more practical alternatives. Cobalt is used instead of nickel and manganese to create nickel manganese cobalt oxide (NMC), one of the most influential attempts. The level of automotive applications has steadily declined due to the rising replacement degree, as shown in Figure 1. Another type of material is NCA, in which Ni and Al have largely replaced Co. Compared to the 12% Co included in the initial NCA-based car battery cells, Panasonic reduced this percentage to 2.8% in more current versions in 2018.

Overall, the Co content has been significantly decreased, lithium-ion battery cell density has virtually tripled over the past ten years, and costs have fallen by over 90% [21], according to Bloomberg NEF. We could construct systems with better capacity and rate capabilities because of technological advancement in the 2010s. However, the batteries still have not accomplished all the requirements necessary to eventually compete with internal combustion engines and fuel cell drive-trains[22–25]. The objectives to further reduce weight, enable a more extended range, enable quicker charging, lower the danger of mishaps, and construct batteries based on more environmentally friendly element compositions are still in place.

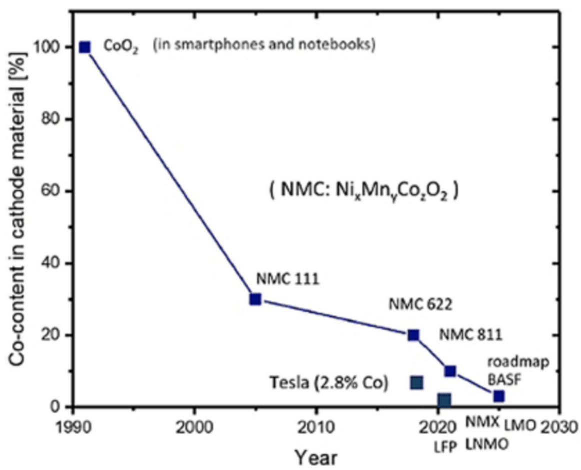

Figure 1. Over time, co-content has increased in traction battery cathode materials [20]. The points have been centered around the apps' release to the market. The current materials LFP (Li-iron phosphate), LMO (Mn spinel), LNMO, and NMX contain 0% Co [19].

Consequently, several techniques have been used to enhance the chemistry of cells and cell design. Different materials chemistries and storage principles are addressed in the ongoing development of cell chemistries, and as a result, the advances exhibit a wide range of maturities. The two most common development paths for cell chemistry are either lithium-based batteries or what are known as post-lithium systems or batteries that rely on the shuttle of other ions rather than Li ions, such as Na, Mg, Ca, Zn, or Al.

Storage capacity, cell voltage, and endurance are these devices' primary goals. As previously mentioned, research in recent years has focused chiefly on developing better, more reliable, and safer cathodes. Due to these projects, several marketed and candidate materials are presently on the market. There is still work to be done in order to create a battery with a dependable high-energy NMC cathode (HE-NMC), hence not all of the materials on the list have reached the required stage of development for use in battery production or chemical testing. While this is going on, it is believed that changing the anode will allow for a significant improvement in cell-level capabilities.

Graphite has been employed as a battery material Since the early Li metal anodes produced dendrites, which caused short circuits and fires in the Li batteries. Graphite might prevent this by safely intercalating the Li ions in the layered carbon host [26, 27]. However, this process reduces the capacity of the lithiated graphite by a factor of ten, from 3861 $mAhg^{-1}$to 372 $mAhg^{-1}$. Additionally, the volumetric capacity of Li metal is 2061 $mAhcm^{-3}$ while that of graphite is 1376 $mAhg^{-1}$. Therefore, the overarching goal of this project is to substitute graphite with a more potent storage substance that may also be based on a different storage principle, reference [28].

The estimated gravimetric capacity of the anode would increase by approximately ten, and one-third of the space could be conserved if a safe means could be found to re-establish the Li metal anode. This might improve the energy capacity of the cell by up to 50% [29–31]; a calculation example is given by Kim [32].

Table 1. Specification of the prototype of BYD Belead battery cell type.

Capacity	202Ah
Normal Voltage	3.2V
Max. Charging Voltage	3.65V
Energy	646.4 Wh
Length	905mm
Height	118mm
Depth	13.5mm
Volume	1.442L
Volumetric Energy Density	448 Wh/L
Gravimetric Energy Density	448 Wh/L
Chemistry	$LiFePO_4$

3 Overview of Blade Battery

The Blade Battery is a new type of lithium-ion battery developed by Chinese battery manufacturer BYD. The Blade Battery is named after its unique shape, which resembles a blade. This battery has several advantages over traditional lithium-ion batteries, including a longer lifespan, higher energy density, and improved safety. The Blade Battery is a new type of lithium-ion battery that offers several advantages over traditional lithium-ion batteries. One of the most significant advantages of the Blade Battery is its unique design. The Blade Battery eliminates conventional battery cells and instead uses a series of thin lithium iron phosphate (LFP) sheets stacked together like a book. This unique design not only allows for a more compact and efficient battery but also improves the battery's thermal stability.

Another advantage of the Blade Battery is its high energy density. The Blade Battery offers a more extended driving range of up to 600 kilometers on a single charge than traditional lithium-ion batteries. This increased energy density is partly due to the battery's unique design, which allows for more efficient use of the battery's capacity. In addition to its high energy density, the Blade Battery also has a longer lifespan than traditional lithium-ion batteries. The Blade Battery has a lifespan of up to 1.2 million kilometers, significantly longer than conventional lithium-ion batteries. This extended lifespan is partly due to the battery's unique design, which reduces the stress on the battery's cells. One of the most significant advantages of the Blade Battery is its improved safety features. Safety is a primary concern for electric vehicle batteries, and the Blade Battery has several safety features that make it safer than traditional lithium-ion batteries. The Blade Battery has a built-in thermal management system that prevents the battery from overheating. The battery has a unique design that prevents thermal runaway, which is the leading cause of battery fires. Overall, the Blade Battery is a significant development in the field of electric vehicle batteries. Its unique design, high energy density, longer lifespan, and improved safety features make it an attractive choice for electric vehicle manufacturers. While the Blade Battery is currently only available in China, it has the potential to become a global standard for electric vehicle batteries, offering a more efficient, longer-lasting, and safer option for electric vehicle owners.

3.1 Design

The Blade Battery has a unique design that eliminates traditional battery cells. Instead, the battery uses a series of thin lithium iron phosphate (LFP) sheets that are stacked together like a book. The sheets are then placed in a rectangular metal case filled with electrolytes. The design of the Blade Battery is one of its most significant advantages over traditional lithium-ion batteries. Unlike conventional batteries that use cylindrical or prismatic battery cells, the Blade Battery uses a unique stacked design that eliminates the need for individual battery cells [33]. The Blade Battery comprises a series of thin lithium iron phosphate (LFP) sheets stacked together like a book, Figure 2 shows the structural design of the blade cell. These sheets are then placed in a rectangular metal case and filled with an electrolyte solution. This unique design has several advantages over traditional lithium-ion batteries. First, the Blade Battery's stacked design allows for a more compact and efficient battery. The battery's rectangular shape means that it can be easily integrated into the structure of an electric vehicle, allowing for more efficient use of space.

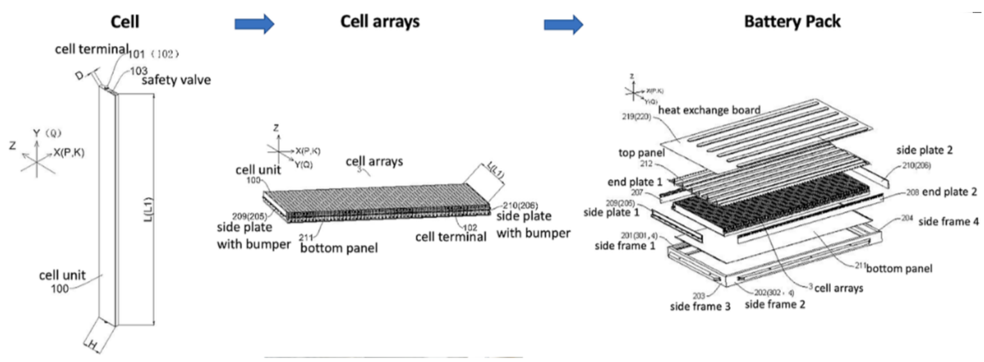

Figure 2. The structural design of blade cell, cell arrays, and battery pack[33].

Second, the Blade Battery's stacked design improves the battery's thermal stability. Traditional lithium-ion batteries are prone to overheating and thermal runaway, leading to fires and explosions. The Blade Battery's stacked design reduces the stress on the battery's cells, allowing for a more stable and reliable battery[34]. Finally, the Blade Battery's stacked design allows for a more flexible battery architecture. The battery can be easily customized to fit the specific needs of different electric vehicle models, allowing for greater design flexibility and efficiency. In addition to its unique stacked design, the Blade Battery has several other innovative features. For example, the battery has a built-in thermal management system that prevents the battery from overheating. The battery also has a unique electrolyte solution less likely to catch fire than traditional lithium-ion battery electrolytes. Overall, the Blade Battery's unique design is one of its most significant advantages over traditional lithium-ion batteries. Its stacked design allows for a more compact, efficient, and flexible battery architecture while improving thermal stability and safety. These features make the Blade Battery an attractive option for electric vehicle manufacturers looking for a more reliable and safe battery for their vehicles.

3.2 Performance

The Blade Battery has a higher energy density than traditional lithium-ion batteries. It can provide a driving range of up to 600 kilometers on a single charge. The Blade Battery also has a longer lifespan than conventional batteries, with a lifespan of up to 1.2 million kilometers. The Blade Battery is more thermally stable than traditional lithium-ion batteries and has a lower risk of catching fire. The performance of the Blade Battery is another significant advantage over conventional lithium-ion batteries. The Blade Battery offers a higher energy density than traditional batteries, which can store more energy in a smaller space. This increased energy density gives electric vehicles a more extended driving range on a single charge, making them more practical and convenient for daily use. In addition to its higher energy density, the Blade Battery also has a longer lifespan than traditional lithium-ion batteries. The Blade Battery has a lifespan of up to 1.2 million kilometers, significantly longer than conventional lithium-ion batteries' lifespan. This extended lifespan is partly due to the battery's unique design, which reduces the stress on its cells and improves its thermal stability [35].

The Blade Battery also has a faster charging time than traditional lithium-ion batteries. The battery can be charged to 80% capacity in just 30 minutes, making it a more convenient option for electric vehicle owners who need to charge their vehicles quickly.

Furthermore, the Blade Battery has excellent performance in extreme temperatures. Traditional lithium-ion batteries tend to lose capacity in cold temperatures and can overheat in hot temperatures, leading to reduced performance and potentially dangerous situations. The Blade Battery's unique design and thermal management system allow it to maintain its performance in extreme temperatures, making it a more reliable option for electric vehicle owners. Overall, the Blade Battery's higher energy density, longer lifespan, faster charging time, and excellent performance in extreme temperatures make it a superior option to traditional lithium-ion batteries. These performance advantages make the Blade Battery an attractive option for electric vehicle manufacturers looking to improve their vehicles' performance and reliability.

3.3 Safety

Safety is a significant concern for electric vehicle batteries, and the Blade Battery has several safety features that make it safer than traditional lithium-ion batteries. The Blade Battery has a built-in thermal management system that prevents the battery from overheating. The battery has a unique design that prevents thermal runaway, which is the leading cause of battery fires. Safety is a critical consideration for electric vehicle manufacturers, and the Blade Battery has several innovative features that improve the safety of the battery. One of the most significant safety features of the Blade Battery is its enhanced thermal stability. Traditional lithium-ion batteries are prone to overheating and thermal runaway, leading to fires and explosions. The Blade Battery's unique stacked design reduces the stress on its cells, improving its thermal stability and making it less prone to overheating. In addition, the Blade Battery has a built-in thermal management system that helps regulate its temperature and prevent it from overheating. Another safety feature of the Blade Battery is its unique electrolyte solution. Traditional lithium-ion battery electrolytes are highly flammable and easily catch fire, even under normal operating conditions. The Blade Battery's electrolyte solution is less volatile than conventional electrolytes, which reduces the risk of fires and improves the battery's overall safety.

The Blade Battery also has a robust battery management system that helps to prevent overcharging, over-discharging, and short circuits. The battery management system monitors its performance and temperature and can shut down the battery if it detects abnormalities. This feature helps to prevent dangerous situations from occurring and improves the overall safety of the battery. Finally, the Blade Battery has undergone rigorous safety testing to meet the highest safety standards. The battery has been tested for impact, crush, and penetration resistance and has passed all of these tests with flying colors. This testing ensures the Blade Battery is safe and reliable for electric vehicle manufacturers and consumers. Overall, the Blade Battery's improved thermal stability, unique electrolyte solution, robust battery management system, and rigorous safety testing make it one of the safest options for electric

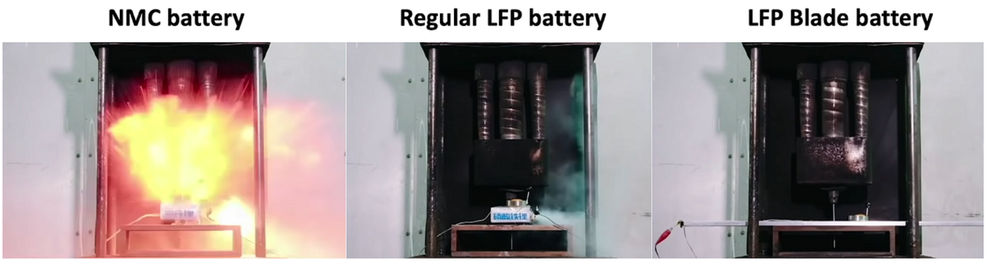

Figure 3. Nail penetration test for NMC, regular LFP, and Blade Battery[33].

vehicle manufacturers. These safety features make the Blade Battery an attractive option for electric vehicle manufacturers looking to improve their vehicles' safety and reliability.

Currently, the Blade Battery is based on LFP. Compared to batteries based on NMC, notably the Ni-rich NMC 811, the LFP battery is significantly safer thanks to its electrochemical properties. The BYD nail penetration test in Figure 3 indicates that the Blade Battery design offers a very high level of safety. NMC batteries readily attain their thermal breakdown temperature of 200°C if a piercing nail brings on a short circuit. Thermal runaway occurs when a significant amount of oxygen is produced during nail penetration. On the other hand, LFP cathodes feature phosphate poly-anions with a rigid crystal structure that is difficult to break down. Even at temperatures above 500°C, only a tiny amount of oxygen is emitted throughout the nail penetration test [33].

When the internal pressure reaches a certain point, safety valves that release electrolytes, gas, and other substances can assist in stopping an explosion. Lastly, a standard LFP battery's surface temperature may be below 240°C. In the test, the Blade Battery cell's surface temperature stayed below 60°C without showing any evidence of smoke, which is a significant improvement over NMC batteries. The Blade Battery has an enormous specific surface area, an unusual ultra-long design, and comparable thermal stability to LFP [33].

As a result, the heat created by the short-circuited area is more easily discharged and is less prone to propagating throughout the cell. Compared to alternative designs of LFP or ternary batteries, a single-cell unit of the Blade Battery is significantly safer in this way.

3.4 Cost

The LFP battery pack is unquestionably less expensive than the NMC battery pack in terms of price. Because of this, despite their lower operating ranges, LFP batteries are used in most electric buses now on the market and early EVs in China. Compared to traditional LFP battery packs, the cost of the battery pack may be reduced by an extra 20% with the help of the Blade Battery design. The price is said to be less than $85 per kWh, which is less than the expected cost of the most recent LFP pack from CATL for the Tesla Model 3 in China (around $100 per kWh). Under China's present strategy, the pack is more competitive thanks to its cheap cost [35].

The Blade Battery pack can attain 140 Wh/kg, enabling it to qualify for the same subsidies as most ternary batteries. The present policy states that LFP battery systems will receive fewer subsidies due to low energy density ($< 140Wh/kg$). The most recent report indicates that BYD and its customers have reserved the 8 GWh annual capacity of the Blade Battery facility in Chongqing. According to a recent analysis by the research firm Wood Mackenzie, the cost of battery packs is expected to fall below $100 per kilowatt-hour by 2024. In 2020, BYD has undoubtedly met its goal.

4 Discussion and Future works

As the electric vehicle (EV) industry evolves, battery technology remains its fulcrum. Our review reveals that the BYD Blade Battery offers a distinct combination of high energy density, advanced architectural design, and safety features, making it a significant player in this evolving landscape. Its prism-shaped cells and LPF composition offer design advantages that enhance safety, a critical concern, especially given the nail penetration tests. While the Blade Battery demonstrates promise, several crucial avenues demand further exploration to substantiate its trans-formative potential:

1. Durability Studies: While immediate performance metrics are impressive, the battery's long-term reliability is yet to be assessed. Future works could explore degradation rates and long-term efficiency.

2. Environmental Analysis: A cradle-to-grave lifecycle analysis would offer insights into the environmental impact, including raw material sourcing, manufacturing, usage, and disposal or recycling.

3. Market Competitiveness: Additional research is needed to compare the Blade Battery to emerging technologies like solid-state batteries. Comparative studies in real-world applications can offer empirical data to gauge its competitive advantage.

4. Economic Feasibility: While preliminary cost analyses are favorable, a more detailed examination of its overall cost-effectiveness in diverse market scenarios is essential.

5. Safety Protocols: Given the initial success in nail penetration tests, comprehensive studies across multiple safety metrics will provide a rounded view of its real-world safety.

In summary, the BYD Blade Battery is poised to impact the EV industry significantly. Yet, its promise must be matched by rigorous, multi-faceted research to confirm its potential to set new industry standards.

5 Conclusion

The BYD Blade Battery is a transformative force in the rapidly evolving electric vehicle (EV) market. This innovation leapfrogs traditional lithium-ion batteries in multiple facets, including energy density, lifespan, and safety measures, notably proven through rigorous nail penetration tests. Although currently confined to China, its potential to set a new global standard is palpable. Significant attributes such as higher energy density, improved thermal stability due to its unique electrolyte, and robust battery management system position it as a formidable option against traditional batteries. These features collectively enhance vehicle reliability and user experience, fast-tracking its adoption. However, it's critical to acknowledge that the Blade Battery is still in its early stages. Detailed studies focusing on long-term durability, global scalability, and safety protocols under various conditions are indispensable for a comprehensive assessment. In conclusion, the Blade Battery isn't merely an incremental improvement; it represents a paradigm shift in EV battery technology. Its design ingenuity and performance metrics make it a vanguard contender in the next-gen EV battery race.

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