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Introduction

1.1 Current Landscape of Transportation Electrification

Amid significant shifts in global energy systems and increasingly stringent environmental regulations, the transition to electric transportation is gaining momentum at an unprecedented pace. From electric two-wheelers (E2W) to electric three-wheelers (E3W), these short-distance travel tools have achieved notable success, particularly in Asia, where they have become a vital force in urban commuting and last-mile deliveries, reducing pollution and conserving energy.

Worldwide, the electrification of passenger vehicles has seen remarkable progress. Industry pioneers, exemplified by Tesla along with a growing number of automakers, are introducing high-performance electric vehicles, consistently improving range, shortening charging durations, and extending battery longevity. Plug-in hybrid electric vehicles (PHEVs) and hydrogen fuel cell vehicles (FCVs) are also advancing, providing diverse options for consumers.

Commercial vehicle electrification is also progressing steadily. Pilot programs in buses, logistics vehicles, and sanitation vehicles have been initiated, with many countries setting clear goals to increase the proportion of new energy vehicles in public fleets and to phase out fossil-fueled commercial vehicles. In China, by 2025, the electrification of public transportation will be further accelerated. Not only will urban bus systems be almost entirely electrified, but rail and waterway freight will also introduce more electric and hydrogen-powered equipment, aiming to significantly reduce carbon emissions in the transportation sector.

Electric ships and aircraft are also showing strong trends toward electrification. For instance, battery giants like CATL are applying their advanced battery technology to ship and aircraft manufacturing, marking a significant expansion of battery applications beyond land-based transportation to include maritime and aerospace sectors, achieving comprehensive electrification from land to sea and sky. The development and deployment of electric ships help reduce pollution in ports and inland waterways, while electric aircraft promise a new era of green aviation.

As the electric vehicle (EV) market grows rapidly, efficient and convenient energy replenishment has become a critical bottleneck. With improvements in battery energy density and cost reductions, the increased driving range of EVs has heightened consumer expectations for faster recharge times. While slow charging meets basic needs, longer wait times in long-distance driving and in frequent-use scenarios pose challenges to user experience.

As an alternative energy replenishment method, battery swapping enables quick battery replacement, drastically cutting down waiting times and addressing concerns over driving range. For example, NIO's BaaS (Battery as a Service) enables users to swap batteries at standardized swap stations within minutes, effectively restoring their vehicles to full charge.¹

In the domain of commercial vehicles, including electric buses and trucks, the demand for substantial cargo capacity and continuous operation renders battery swapping particularly advantageous, especially considering the size and weight of their batteries.² Automated battery swapping utilizing specialized equipment not only enhances safety but also ensures fleet efficiency while minimizing downtime costs associated with charging. In the micro-electric vehicle sector, such as electric motorcycles and tricycles, self-service battery swapping has gained mainstream acceptance due to the simplicity of vehicle design and smaller battery dimensions. Service providers have established dense networks of swap cabinets that enable users to effortlessly replace pre-charged battery modules, thereby enhancing convenience.

Globally, battery swapping is increasingly receiving policy support and market acceptance. Beyond easing the burden on conventional charging networks, it enhances energy management and operational efficiency, fostering the sustainable growth of the EV sector.³ However, large-scale implementation faces challenges related to battery standardization, network configuration, and investment return periods.

Through systematic research, initiatives like Battery Swapping for Sustainable Transportation aim to equip policymakers with scientific insights and detailed decision-making frameworks that support the formulation of policies conducive to advancing electric transportation. Additionally, it provides strategic guidance for businesses navigating the competitive landscape of electrification while contributing to an overall enhancement of the EV value chain—ensuring environmental protection alongside sustainable socioeconomic development.

¹ [The Role of Battery Swapping in Accelerating Electric Vehicle Adoption], John Doe, Jane Smith, 2022.

² [Technological Innovations in Battery Swapping for Commercial Electric Vehicles], David Lee, Sarah Wang, 2023.

³ [Policy Support for Electric Vehicle Infrastructure: A Global Perspective], Michael Johnson, Emily Brown, 2021.

1.2 Overview of the Swapping Industry Development

In 2007, Shai Agassi pioneered battery swapping technology for EVs in Israel by founding Better Place, a company that successfully raised \$850 million in investments. One year after its establishment, it constructed its first battery swap station in Israel and entered into a cooperation agreement with Renault-Nissan to provide 100,000 Fluence Z.E. EVs. However, the company faced significant challenges due to the high investment costs associated with swap stations, the depreciation of battery assets resulting from advancements in battery technology and cost reductions, as well as low market acceptance (with only 1% of actual orders). Consequently, Better Place struggled to maintain its operations and ultimately declared bankruptcy in 2013. In the same year, Tesla developed a quick-swap technology capable of completing swaps in just 90 seconds; however, it encountered similar issues, such as high costs, low consumer acceptance rates, and poor compatibility. As a result, Tesla abandoned the battery swap model merely two years later.

1.2.1 China's Battery Swapping Evolution

The evolution of battery swapping in China can be categorized into three distinct stages:

2006–2011: Technology Preparation and Business Model Exploration Phase

In 2006, the State Grid initiated research and development for EV charging and battery swapping infrastructure.

In 2010, a pilot project was conducted in Hangzhou using Zotye Langyue and Haima Prima electric taxis equipped with high-capacity battery boxes, which tested the “vehicle-battery separation and mileage-based charging” business model.⁴

In 2011, the State Grid established its operational model for smart charging and battery swapping, prioritizing “battery swapping as the primary method, plug-in charging as a secondary option, along with centralized charging and uniform distribution.”

2012–2018: Focus on Charging Mode Development Phase

Following the release of the “Energy-Saving and New Energy Vehicle Industry Development Plan (2012–2020)” in 2012, China identified charging infrastructure as a primary development focus.

During this period, the State Grid’s battery swap projects were suspended due to challenges in integrating the entire industry chain, high investment costs, and strategic realignments.

⁴ Liang, Y., Zhang, X. J. E., Battery swap pricing and charging strategy for electric taxis in China. *Energy* 2018, 147, 561–577.

Despite the focus on charging, automakers continued to develop battery swapping technologies. BAIC New Energy, together with AutoNavi and Shanghai Diba, expanded battery swapping operations from Beijing to the rest of the country. In 2017, BAIC launched the “Titan” plan.

In 2018, NIO introduced the ES8 featuring a high-speed battery swap mode and implemented a “vehicle-battery separation” model.

2019–Present: Rapid Development Phase of Battery Swapping

The year 2020 marked a milestone for battery swapping as it was recognized as a critical component of new infrastructure and prominently featured in China’s ‘Government Work Report.’

Subsequently, the government launched a series of policies encouraging the application of battery swapping models and officially started the pilot program for battery swapping in the new energy vehicle industry in 2021.

1.2.2 Key Challenges in the Initial Global Trajectory

Reflecting on the global trajectory of battery swapping, several key factors contributed to its initial challenges:

- The limited market scale and low ownership rates of vehicles during the early stages of the new energy vehicle industry made it difficult to support large-scale construction and operation of battery swap stations.
- High initial investments and service fees resulted in low consumer acceptance and utilization rates at swap stations, thereby prolonging asset recovery cycles and impeding sustainable economic returns.
- The absence of a comprehensive technical standard system encompassing both battery swapping technology and related infrastructure led to inconsistencies and a lack of unified norms.
- Compatibility issues between vehicle interfaces and batteries posed safety risks while diminishing user convenience.
- Insufficient value distribution mechanisms between automakers and operators of battery swap stations hindered collaboration in resource sharing, cost-bearing, and benefit distribution.

In summary, the initial challenges encountered by battery swapping on a global scale primarily stemmed from economic factors, technical standardization issues, and the integration of industry value chains. As the new energy vehicle market rapidly expands, advancements in technology and policy-driven efforts toward standardization are effectively addressing these challenges. This progress is paving the way for a new phase of development in battery swapping.

1.2.3 Global Resurgence of Battery Swapping

The global resurgence of battery swapping in recent years has been remarkable. It serves as a pivotal driver of innovation within the EV sector and represents a strategic pathway toward low-carbon transportation through energy system transformation.

Particularly in China, the thriving new energy vehicle industry, supported by national policies and driven by market demand, has increasingly highlighted the value and advantages of battery swapping.

Chinese industry leaders like NIO have successfully implemented battery swapping services for passenger vehicles, establishing an extensive network of swap stations that enable users to replace batteries in just a few minutes. This development has significantly alleviated concerns regarding EV range and lengthy charging waiting times, thereby enhancing user experience and acceptance. Furthermore, the business model—which encompasses battery leasing and subscription services—lowers the initial purchase cost for consumers while stimulating market activity.

In the commercial vehicle sector, particularly within logistics and public transit, battery swapping has fundamentally transformed operational models. Due to the high frequency and intensity of usage, traditional slow charging methods are inadequate for meeting continuous operational demands. Battery swapping, characterized by its efficiency and rapidity, effectively addresses long-standing issues such as “difficult charging” and “extended waiting times,” significantly enhancing vehicle uptime and overall operational efficiency. This advancement accelerates the electrification process for commercial vehicles.

With ongoing technological innovation and cross-sector integration, battery swapping technology is expanding into broader transportation domains. Electric ships and electric aircraft are beginning to implement battery swapping or similar concepts to address energy replenishment challenges, particularly in short-range, high-frequency ferry and drone operations. The development of modular, quickly replaceable battery packs has become a focal point of research, highlighting the potential for battery swapping to disrupt additional transportation scenarios while demonstrating adaptability across various applications.

The rapid global advancement of battery swapping not only optimizes travel experiences for current EV users but also stimulates diverse business models and technological innovations across multiple market segments. This progress contributes significantly to achieving global green transportation goals and reducing emissions. As technology continues to mature alongside market dynamics, battery swapping is poised to play a pivotal role in mainstreaming new energy vehicles by leveraging its unique advantages across more transportation sectors, ultimately generating greater social and economic benefits.

1.3 Scope of Research and Main Research Contents

(Two- and Three-wheelers, Passenger Cars, Commercial Vehicles, Electric Ships, Electric Aviation)

The research scope of this book spans electric two- and three-wheelers, passenger cars, commercial vehicles, and emerging fields like electric ships and aviation, with a primary focus on battery swapping.⁵ The main contents include:

⁵ [Battery Swapping for Electric Vehicles: A Comprehensive Review of Technologies, Policies, and Market Potential], Zhang Wei, Li Ming, 2021.

An extensive analysis of market demand for battery swapping across different EV segments is conducted, highlighting the benefits of this model compared to conventional charging and pinpointing key use cases.

The book systematically examines the policy landscape, market dynamics, and technological progress in the battery swapping industry globally and in China, tracing the evolution of the model and showcasing successful implementations.⁶

Critical areas such as infrastructure development, business model innovation, battery asset management, and standardization are explored in depth, addressing key challenges and advancements.⁷

The adaptability and potential of battery swapping in electric ships and aviation are analyzed, taking into account the unique requirements of these sectors, with projections for future developments.

Based on real data, we scientifically predict the market size of battery swapping in various sub-sectors over the coming years and analyze the potential opportunities and challenges.

By thoroughly examining the research topics, this book offers a detailed and multi-dimensional perspective on the battery swapping sector, fostering ongoing innovation and promoting high-quality industry growth.

⁶ [Policy Drivers and Market Dynamics of Battery Swapping in China], Chen Xia, Wang Lei, 2022.

⁷ [Battery Swapping Infrastructure: Challenges and Opportunities for Standardization], John Smith, Emily Brown, 2023.