

Secondary use of electric vehicle batteries and potential impacts on business models

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Abstract *The universal market adoption of electric vehicles (EV) is still impeded by the high cost of lithium-ion (Li-ion) batteries. Repurposing EV batteries in second use applications could help reclaim a portion of initial cost and potentially reduce upfront EV costs. Further, second-life batteries could make EV technology more sustainable in terms of cleanliness of electricity mix for EV charging through storage and grid integration of renewables and of alleviating environmental concerns over battery disposal. This paper presents business models of different EV industry stakeholders that facilitate battery reuse. Based on original interviews with directors and managers from various EV sectors, as well as industry/company reports and academic literature, we analyse the deciding factors for different battery “post-vehicle” applications and their potential impacts on EV business models. The findings emphasize the importance of battery ownership, inter-industry partnerships and policy support on battery secondary use. The results also suggest the potential of battery reuse as a catalyst for EV business model reconfiguration.*

1. Introduction

1.1 Background

In the last few decades, global concerns over climate change have strengthened the need to develop sustainable transportation to reduce greenhouse gas emissions (GHGs). Current policies and government subsidies in China and other countries are trying to stimulate the renaissance of electric vehicles (EV) and help it gain a market foothold. Despite the rapid increase in EV market share recently, this nascent industry still needs to sustain itself in order to have a long-term commercial viability [1]. Nevertheless, the high cost of the battery is considered to be the major factor limiting EV market adoption. The commercialization and economic viability of EV depends on cost-effective, high performance batteries which constitute approximately 1/3 to a half of current EV costs. Typically, an EV battery reaches its end-of-life (EOL) and replacement is recommended when its remaining capacity is below 80% of a new one [2]. When a battery fails to meet the criteria for automotive

service upon its EOL, there is still sufficient energy and power capacity left to support less demanding applications such as load levelling, renewable energy storage and integration, back up power and transmission support [1], [3], [4]. Finding proper scenarios for battery second use could also be important in generating alternative revenue streams and potentially offset the high initial cost of EVs.

Generation and storage renewables from intermittent resources such as wind and solar energy are currently challenging due to the lack of large-scale energy storage systems (ESS) [5]. However, reusing “spent” batteries could provide a promising solution at an inexpensive cost. The integration of renewables into power generation also helps EV’s reputation as “zero-emission” vehicles in terms of charging sources. Further, battery reuse could postpone the recycling phase, which entails costs and potential waste. Repurposing EOL batteries for second use increases their total service life, which slows down the rate of resource exploitation and waste disposal.

1.2 Related Work and Aims

This paper draws on the strategic management literature on business models. Every business enterprise operates under a certain business model, explicitly or implicitly, that explains the value creation, value delivery and value capture mechanisms of its business [6], [7]. Teece describes business model as a conceptual model of business which articulates the underlying logic required to create and deliver value to customers, and earn a profit from various value-related activities [6]. Amit & Zott, however, explain business model in a much more concrete and precise fashion [8]. Focused mainly on e-business, they refer to business model as a unifying unit of analysis which “depicts the design of transaction content, structure and governance so as to create value through the exploitation of business opportunities”. Realizing that transaction connects activities, this definition further evolved as “a system of interdependent activities that transcends the focal firm and spans its boundaries” [9]. Researchers tend to develop their own perspectives of what a business model is from different areas and a widely accepted common language of business model has yet to be reached. By and large, there are mainly two streams of definition: value-oriented and activity-oriented business models [13]. Although there is no consensus on the definition and elements of a business model, related researches converge in key areas: the existence of value proposition, value chain configuration or value network, the cost and revenue streams [10]–[12]. In this study, business model is defined as the logic of value exchange within the network of stakeholders. And a business model perspective is taken to examine the battery secondary use.

The technical and economic feasibility of battery reuse have been discussed and analysed by many authors [1]–[3], [14]–[16]. Private companies and research institutions have initiated pilot projects repurposing retired EV batteries in ESS for

example into solar panels and wind farms, household and public back up power, load levelling, and other secondary use applications [17][18]. There were no major technical barriers found, while the economic viability of reuse in practice should be further studied [19]. Few authors to date, however, have examined EV battery second life at the business model level.

Given the research gap mentioned, this paper aims to investigate how to help EV stakeholders maximize the value of used EV batteries from a business model perspective. Four cases of business models facilitating battery reuse were studied and the deciding factors for battery repurposing were analysed. Battery ownership, supportive policies and inter-industry partnership were shown to be critical for the commercial success of battery reuse. The interaction of business models and battery reuse were also observed from case studies. The research shows a trend of increasing awareness of companies to incorporate EOL battery reuse into their business models.

2. Research Design

2.1 Research objectives and methodology

The research gap mentioned in section 1.2 highlighted the paucity in EV battery second use research from a business model perspective. Current understanding of EOL strategies is mostly presented in the form of technical or economic analysis and is limited on a firm-centric level. This research aims to extend previous work on this issue from a systematic, multi-stakeholder aspect. It also contributes to understanding how EOL strategies could potentially enable a green technology to achieve real sustainability through the platform of business models.

The above research objective is developed into the following research questions:

1. What are the deciding factors for EV battery secondary use?
 2. How are EV stakeholders designing their business models for battery reuse?
 3. How do EV business models and EOL battery reuse interact with each other?
- In this study, the case study method is used to address these research questions, which I explain in the next section.

In addressing the above research questions, the methods used in this research – case studies and semi-structured interviews will provide a contextual understanding of the research topic. Case study research is well adapted to answer the “how” type research questions in early innovation strategies [20]. The use of qualitative case study research methodology is justified by the uncertainty of the emerging industry studied, along with the uncertain and exploratory nature of the research topic [21].

2.2 Case selection

Companies representing different stakeholders in the EV industry were chosen (Table 1) and cases were analysed through secondary data (academic articles, industry/company reports) and semi-structured interviews. The four industry players are EV manufacturer, recycling company, charging infrastructure and battery reuse joint venture.

Table 1. EV battery second use case studies

Company/ Joint venture	Role as stakeholder	Country	Business model
Yinglong Energy	EV manufacturer	China	Financial leasing
Brunp	EOL vehicle recycle	China	Battery recycling
FreeWire	Charing infrastructure	USA	Mobile EV charging
4R Energy	Battery reuse	Japan	Commercial energy storage

3. Case Studies

3.1 Yinlong Energy (Zhuhai) – Battery reuse in ESS

Yinglong Energy (YLE) is one of the largest new energy enterprises in China. Since its establishment in 2009, YLE aims to build a closed-loop industrial chain from battery materials, lithium-ion (Li-ion) battery manufacturing, and two strategic industries – pure electric vehicles (mainly electric buses) and ESS, to EOL management. Based on a financial leasing business model, YLE sells electric buses to the financial institute, who then rent the EVs to bus companies. During the 10-year tenancy, YLE provide free maintenance for those rented EVs under the contract. Upon expiry of the tenancy, YLE will take back the EVs from bus companies including the traction batteries. Though this business model does not explicitly reflect battery EOL strategies, it implies YLE's control over the battery (or battery ownership) during the after-sale service and EOL contract. Besides, the other industrial chain ESS provides YLE with capabilities and scenarios to reuse EOL batteries. To make commercial business cases in terms of reusing EV batteries in ESS for load leveling, however, policies and regulations in China regarding peak-valley price difference are required.

3.2 Brunp (Foshan) – Battery recycling

Brunp is a state-level recycling enterprise committed to the resource recycling of retired batteries and scrapped cars, as well as high-end battery materials production. With a 10-year tradition of recycling scrapped conventional vehicles and batteries from portable electronics, Brunp has established sound relationships with its customers such as car companies, battery manufactures and the public. Based

on its customer relationships, Brunp has been trying to reconfigure their business models to collect used EV batteries. However, Brunp is now facing challenges regarding EV battery reuse. The most important barrier is the limited access to retired EV batteries. In order to reuse EV batteries on a large scale, partnership with other EV stakeholders is essential. Moreover, regulations about battery liability and policy incentives can also make a difference in reuse viability.

3.3 FreeWire (California) – Mobile EV charging service

FreeWire is the first solution to combine EV charging with grid-level energy management by creating a network of grid-smart mobile EV chargers using second-life batteries. Mobi Charger, a mobile and portable charging station, utilizes retired batteries from the Nissan Leaf. Based on a charging service business model, FreeWire could save charging costs for customers through its storage capability and the grid peak-valley price spread. By acting as a cost-effective smart buffer between EVs and utilities, they create great value through grid storage, load levelling, and demand response. Taking advantage of the low cost and remaining capacity from retired Leaf batteries, as well as the partnership with Nissan, FreeWire's innovative business model could have the potential to scale the flexible charging infrastructure, providing an energy service that benefits both customers and the grid.

3.4 4R Energy (Yokohama) – Joint venture for EV battery reuse

4R Energy, a joint venture by Nissan and Sumitomo, is the first company to address the secondary use of EV Li-ion batteries. Utilizing exclusively EOL Nissan Leaf batteries repurposed by 4R Energy, Sumitomo has established the world's first large-scale power storage system on Yume-shima Island, Osaka [22]. A prototype system (600kW/400kWh) consists of sixteen used EV batteries is used to test the soothing effect on the power output from a nearby wind farm. The partnership between Nissan and Sumitomo and the establishment of the joint venture thereof indicate battery second use as being a catalyst for business model innovation and even new businesses.

4. Discussion

4.1 Deciding factors for battery second use

From the case studies of the four companies, we have observed three common deciding factors for EV battery second use: battery ownership, government support and partnerships. Case studies, especially with YLE and Brunp, indicate the control over battery as a prerequisite for all business cases. Different countries and regions may have different answers when it comes to "Who is responsible for EOL EV batteries". Though EOL products have long been considered as a burden to be avoided by companies, second-life batteries could potentially, in the future, become

a rich stream of profit. Therefore, it makes a difference that policy makers clarify the EOL battery liability. Second, government should offer financial incentives to support second-life demonstration efforts and encourage pilot projects in promising second use applications. Administrative barriers should be reduced, such as access to the grid with load levelling tests and peak-valley electricity price spread in favour of profitable ESS. Given the complex nature of second-life batteries and their wide potential applications, a multi-stakeholder perspective is suggested and inter-industry partnership is justified as a key factor for battery reuse success.

4.2 Impact of battery second use on business models

Case studies with incumbent firms such as YLE and Brunp brought insight into the impact of current business models on battery reuse strategies. YLE's business model helps retain its battery ownership through leasing contract and maintenance service while Brunp highly relies on battery sources from outside. Both companies are trying to find new value opportunities for EOL batteries, either through internal capability reinforce or external partnerships, which indicate the tendency of business model modification stimulated by battery second use. For start-ups or joint venture like FreeWire and 4R Energy, repurposing EOL batteries gives rise to business model innovation or even new businesses.

4.3 Limitations and Future Research

This research aims to contribute to literature on business models and sustainable technology through an empirical exploration of EOL strategy and business model interaction in the case of EVs and battery reuse. Although some initial findings are observed from the case studies regarding the deciding factors for battery reuse and their potential impacts on business models, this study has several limitations. Firstly, due to the limited EV market share (limited battery volume for large-scale secondary applications) and economic uncertainty of battery secondary use, the practice of repurposing EOL batteries is still rare in the EV industry. This suggests the limited data availability and generalizability of our findings. Secondly, the study has limitation in identifying all the key stakeholders in this emerging industry over a relatively short time period. To mitigate these problems, the author decides to conduct deeper case studies on the extent stakeholders and identify potential key players in the EV industry. More importantly, the limitations also suggest that future research in effective business models for both EVs and battery second use, and their interactions could potentially achieve their mutual promotion and spur other stakeholders in the whole industry. In a nutshell, developments in EV business models and battery second use, as well as their interplay is worth further research, given the limited but ever-increasing volume of EVs and emerging stakeholders interested in battery second use.

5. Conclusion

In summary, this paper has investigated literature and current practices related to EV battery second use. Based on four qualitative case studies with YLE, Brunp, FreeWire and 4R Energy, the deciding factors for different stakeholders to repurpose EOL batteries have been analysed. Among various factors that influence battery reuse, the battery ownership, government support as well as inter-industry partnership were identified as common deciding factors for second use feasibility. Moreover, the role of the innovative business models in the success of repurposing EOL batteries has been studied. Case studies showed that current business models of incumbent companies could facilitate or slow down battery second use. Meanwhile, the efforts to develop second use business cases could modify current business models. As new stakeholders in EV industry, FreeWire and 4R Energy cases indicated that in the long run, EOL strategies could have the potential to innovate current EV business models and even create new businesses.

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