Analysis of Battery Swapping Technology for Electric Vehicles – Using NIO's Battery Swapping Technology as an Example

Yusheng Zhang*

College of Engineering, Northeastern University, 360 Huntington Ave, Boston, MA 02115

ABSTRACT: The electric vehicle (EV) industry is growing rapidly at the moment. However, refueling an electric vehicle could be a time-consuming process. This was the case until the emergence of battery swapping technology. Using the battery swapping technology developed by EV manufacturer NIO as an example, this paper aims to analyze the history, current state, and future of the technology. In order to conduct the analysis, data provided by the EV industry is closely examined, as data from NIO is compared with data from other aspects of the EV industry. Through the analysis, it is found that the battery swapping technology provides efficiency and convenience, but is of high cost and lacks adequate infrastructure on a larger scale. Battery swapping technology has a promising future, but in order to effectively compete with conventional technologies such as charging stations, it would be beneficial for the technology to cut down on cost and expand its infrastructure.

1. INTRODUCTION

Electric vehicles (EVs) are widely used around the world. However, charging an EV could be quite time-consuming. Battery swapping technology is developed in order to resolve this issue, as the drained battery inside an EV could be replaced with one that is fully charged. Based on its past and current state, the future of battery swapping technology would continue to be promising if its current issues could be properly resolved.

Battery swapping technology has been around for quite some time and has started to boom recently due to the rapid growth of the EV industry. Although the technology has matured over the years, it is still relatively new compared to other battery-related technologies such as charging stations. For that very reason, battery swapping technology exhibits a tremendous amount of potential. But on the other hand, the technology also has its unrealized downsides. As battery swapping technology takes a more dominant role in the EV world, this article intends to uncover its potential and hidden weaknesses by investigating the history, current state, and future of the technology. Using Chinese EV manufacturer NIO's battery swapping technology as an example, data regarding refueling time, cost, and amount of infrastructure is inspected. Battery swapping technology has the potential to dominate the EV industry in the future. For that to become reality, it is important for the technology to maintain its strengths and eliminate its weaknesses.

2. BACKGROUND INFORMATION OF BATTERY SWAPPING TECHNOLOGY AND CHINESE EV MANUFACTURER NIO

The battery swapping technology was first developed in 2007 by an Israeli startup named Better Place [1]. The company paired up with French carmaker Renault to launch an electric sedan with battery swapping features, it also built battery swap stations to perform the battery replacement procedure on its electric sedans. Due to limited market demand at the time, the product received very limited market demand. As a result, a better place filed for bankruptcy in 2013 [1].

The technology is currently dominated by Chinese EV manufacturer NIO. Since its founding in 2014, NIO has been involved in developing electric vehicles that possess battery swapping capabilities. Similar to Better Place, NIO also developed battery swap stations as its first one opened in 2018 in Shenzhen, China [1]. The system developed by NIO has seen much success. With 700 completed battery swap stations in China in 2021 [1], the company continues to expand its operations within China and overseas.

Despite its current success, the battery swapping system developed by NIO is not perfect. In order to accurately project its future, its operation, strengths, and weaknesses need to be further examined.

*Corresponding author. Email: zhang.yus@northeastern.edu

3. ANALYSIS BATTERY SWAPPING TECHNOLOGY IN THE PRESENT DAY

The core of the battery swapping technology is the battery swap station. A battery swap station is a location where the discharged battery of a vehicle could be instantly replaced with a fully charged one, eliminating the delay due to the charging of the vehicle's battery [2].

Since NIO is a leader in this technology at the moment, the battery swapping technology it has developed is an appropriate representation of the current state of this technology. Using battery swap stations developed by NIO, this part would determine the status of this technology today by examining its operation and analyzing its strengths and weaknesses.

3.1. Operation of Battery Swapping Technology

A labeled concept drawing of a typical battery swap station developed by NIO is displayed below in Figure 1. Core components of such a battery swap station include the Flexible Locking and Unlocking Platform, drills for battery replacement procedures, and the battery storage compartment [3].

Figure 1 Labeled concept drawing of battery swap station developed by NIO [3]

To swap a drained battery, an electric vehicle would first enter the battery swap station and be placed in the Flexible Locking & Unlocking Platform. The drills would then remove the screws that attach the batteries to the vehicle, the displaced battery would travel on a conveyor belt into the battery storage compartment. Meanwhile, the battery storage compartment would also send a fully charged battery through the conveyor belt back to the platform. The drills would then install this battery into the vehicle, which completes the battery swapping process. As of January 2021, there are already at least 800 such battery swap stations around China, that number will continue to grow [3].

3.2. The Advantages of Battery Swapping Technology

The most significant advantage of the battery swapping technology would be the increased efficiency in the refueling process for electric vehicles. To charge an EV with an average household outlet of 120V, also known as Level 1 charging, an EV would gain a range of 3-5 miles per hour [3]. Given these statistics, assuming a specific electric vehicle could gain 4 miles of range per hour using a household outlet, it would take 25 hours just for the vehicle to gain 100 miles of range. If an EV is charged at a Level 2 charging outlet available at most conventional charging stations, it would take 6-12 hours for the vehicle to fully charge [3]. With Level 3 charging, also known as DC fast charging with over 480V of power, it could still take up to approximately 45 minutes to get to an 80% charge [3].

On the contrary, an electric vehicle manufactured by NIO would spend 277s (4.6min) in a battery swap station to replace its discharged battery [4]. It is also worth noting that parking is included in this timeframe, further emphasizing the increased efficiency battery swapping technology has provided.

Based on the data above, Figure 2 below is created to display the refueling times for vehicles using different methods.

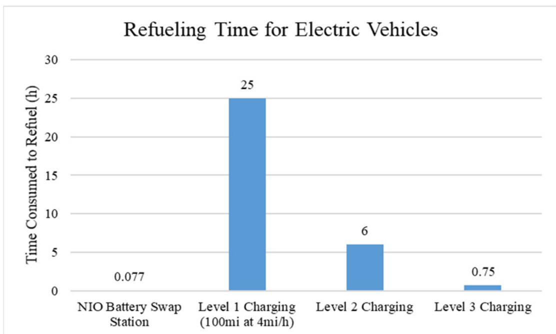

Figure 2 Refueling time for electric vehicles using different methods

Given the data gathered above and cases presented in Figure 2, it is determined through calculations that NIO's refueling process through battery swapping is 99.7% faster than refueling through Level 1 charging, at least

98.7% faster than refueling through Level 2 charging, and approximately 89.7% faster than Level 3 DC fast charging. Through these statistics, it is clear that the battery swapping technology could provide much increased efficiency in the refueling process of an electric vehicle.

3.3. The Downsides of Battery Swapping Technology

Despite the high efficiency of NIO's battery swapping system, it would also have its weaknesses. The biggest disadvantage of the system is the high cost that is associated with having such advanced and complex battery swapping facilities.

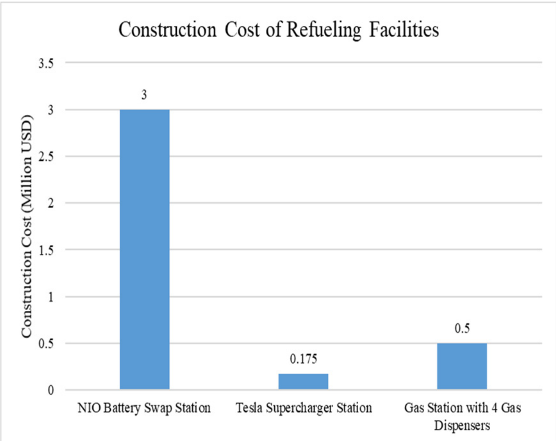

Figure 3 Construction cost of refueling facilities

The construction cost alone of one such battery swap station amounts to be $3,000,000 [5]. In comparison, it would only cost between $100,000 and $175,000 to construct a Tesla Supercharger Station [6], and $500,000 to construct a new gas station with four pumps [7]. To present this cost difference visually, Figure 3 above is created based on this data.

Given the data, it could be found through calculations that the construction cost of building NIO's battery swap station is 5 times more expensive than that of a station, and a minimum of approximately 16 times more expensive than that of a Tesla Supercharger Station. The factor of high cost contributes to the limitation of the amount of battery swapping infrastructure that is available to the growing number of electric vehicles.

Besides cost, the limited resources available inside a battery swap station are also disadvantageous. Since there is one spot per station, only one vehicle is allowed at a time, while there are usually multiple spaces available at an EV charging station or a gas station. A typical battery swap station developed by NIO has 13 batteries stored in the facility, which would allow up to 312 swaps per day [3]. This number is dwarfed when compared to the 1700 vehicles that visit a conventional gas station per day on average [8]. For the betterment of the battery swapping technology in the Future, these weaknesses would need to be amended.

4. FUTURE DIRECTIONS AND RECOMMENDATIONS FOR BATTERY SWAPPING TECHNOLOGY

The battery swapping technology will continue to expand in the future, as NIO aims to reach 3000 battery swap stations in China by 2025 [5], up from the current 800 as of January 2021 [3]. NIO is also going to expand its battery swapping services outside of China, as it opened its first battery swap station in Norway in 2019, and plans on having 20 such stations in 2022 [4]. Currently, NIO also has 534 power charger stations and 600 destination charger stations around China [1]. Based on this data, Figure 4 below is created to visually present the distribution of NIO's refueling facilities.

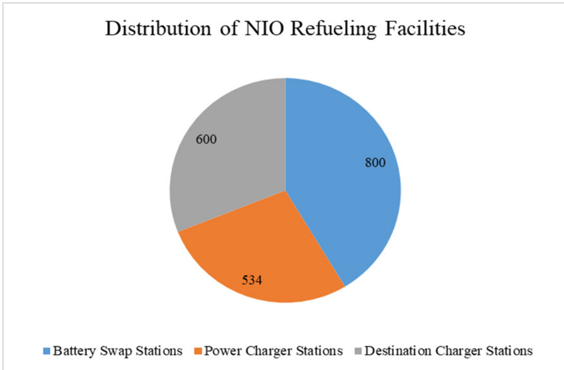

Figure 4 Distribution of NIO's refueling facilities

According to the figure and the data presented, battery swap stations take up 41% of all of NIO's refueling facilities. With the planned increase of battery swap stations around the world, battery swapping could soon become the dominant type of refueling method at least for NIO's vehicles.

Expanding battery swapping infrastructure should be a priority, not only for NIO but for the battery swapping technology in general. Using China as an example again, as of today, the number of charging stations in the country still significantly surpasses the number of battery swap stations available, as there is over 430,000 third-party charging sites available to EVs in all of China [1]. Figure 5 below is created based on this data.

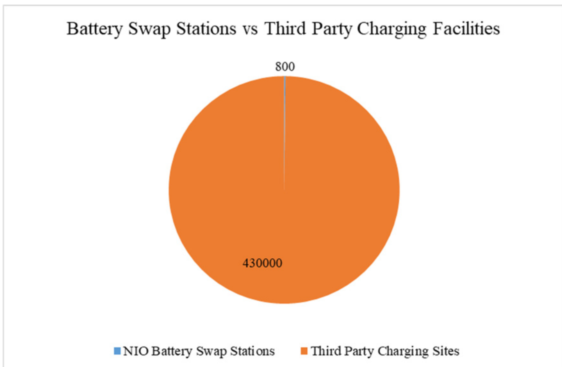

Figure 5 Battery swap stations vs. third party charging facilities in China

According to the Figure and data presented, it could be determined through calculations that battery swap stations would only be approximately 1.8% of the total number of refueling facilities available to electric vehicles in China. Even though battery swapping may be dominating within NIO in the near future, it still has a long way to go before it could dominate the whole EV industry. This further confirms the point that expanding battery swapping infrastructure is key to the future of this technology, and NIO is headed in the right direction.

Given its agenda to increase the amount of battery swapping infrastructure, it would be crucial for NIO to cut down on the cost of building these battery swap stations. Since NIO still dominates the technology today, its ability to resolve the issue of the cost would also play an important role in the fate of the battery swapping technology overall.

Maintenance is another important aspect that could significantly affect the future of this technology one way or the other. Since the technology is relatively new, so are the battery swap stations. Furthermore, properly maintaining them will be beneficial in the long run. Similarly, it is equally important to appropriately maintain the connections between the battery and the vehicle itself. Management of the batteries would also be needed. For the Lithium-Ion batteries used by EVs to remain within their ideal temperature range, proper coolants need to be applied, whether from the vehicle itself or the stations. So far no evidence or reports have suggested that these critical factors have brought problems upon NIO or the technology, but since these factors are key to the technology, they would always be worthy to pay attention to.

Overall, the future of battery swapping technology will be promising. The technology revived despite the initial failure from Better Place. The rapid expansion and growth of NIO fully demonstrate the potential of battery swapping technology. With governmental policies leaning towards the development of EVs [11], the growth of this technology will also be supported by policymakers around the world. Furthermore, companies other than NIO have come up with their own battery swapping systems, demonstrating high faith that the tech industry has towards this technology. CATL from Ningde, China launched its battery swap service for EVs in January of 2022 [9]. In response, NIO has also announced that it will open up its battery swapping services to electric vehicles made by other companies [10]. This demonstrates the fact that the entrance of other companies into the field would create competition, but that would also spark further innovation and drive the development of the technology forward. It is truly exciting to see what the future of battery swapping has to offer, as the industry gradually resolves its current issues and continues to mature on its journey ahead.

5. CONCLUSION

Battery swapping technology is a booming industry that exhibits much potential for the future. Based on the analysis conducted throughout this article, it is clear that the technology reduces refueling time significantly for EVs, but would solutions regarding its high cost and inadequate infrastructure. To improve upon the research done in this paper, more analysis could be done regarding the biasedness of data, and more objective data should be collected. Since the technology is still relatively new, there is also an insufficient amount of data on its overall performance. In the future, more data should also be collected on the performance of battery swapping technology in order to further examine successes and failures.

REFERENCES

1. Nio. (2022, January 21). A brief history of battery swapping. NIO. Retrieved January 25, 2022, from https://www.nio.com/blog/brief-history-battery-swapping
2. Paulraj, P. (n.d.). Comprehensive guide to EV battery swap: Benefits & reasons why it didn't scale up. E. Retrieved January 23, 2022, from https://www.emobilitysimplified.com/2020/06/comprehensive-guide-ev-battery-swap.html
3. Nio Power. -NIO Power. (n.d.). Retrieved January 25, 2022, from https://www.nio.com/nio-power
4. Kane, M. (2021, November 14). Nio installs its first battery swap station in Norway. InsideEVs. Retrieved January 23, 2022, from https://insideevs.com/news/547629/nio-battery-swap-station-norway/#:~:text=The%20the%20second%2Dgeneration%20Power,per%20swap%20(including%20parking)
5. Analyst says battery swap stations won't put big financial strain on NIO. CnEVPost. (2021, October 8). Retrieved January 23, 2022, from https://cnevpost.com/2021/10/08/analyst-says-battery-swap-stations-wont-put-big-financial-strain-on-nio/#:~:text=NIO's%20single%20second%2Dgeneration%20battery,of%20about%20312%20times%2Fday.
6. Etherington, D. (2013, July 26). Inside Tesla's Supercharger Partner Program: The costs and commitments of electrifying road transport. TechCrunch. Retrieved January 23, 2022, from https://techcrunch.com/2013/07/26/inside-teslas-supercharger-partner-program-the-costs-and-commitments-of-electrifying-road-transport/
7. Gas station construction company services. CommTank. (n.d.). Retrieved January 23, 2022, from https://www.commtank.com/services/gas-station-construction-company/#:~:text=The%20average%20cost%20of%20a,accessories%20is%20%24200%2D%24300K.
8. Voelcker, J. (2015, August 26). Gas, electricity, hydrogen: How many cars can 'fuel' and what will it cost? Green Car Reports. Retrieved January 23, 2022, from https://www.greencarreports.com/news/1099548_ga

s-electricity-hydrogen-how-many-cars-can-fuel-and-what-will-it-cost

9. Person. (2022, January 18). China's CATL launches battery swap service for Electric Cars. Reuters. Retrieved January 23, 2022, from https://www.reuters.com/technology/chinas-catl-launches-battery-swapping-service-brand-evogo-2022-01-18/
10. Lambert, F., & Fred Lambert. (2021, July 9). Nio announces plan to open battery swap stations to other electric automakers – any takers? Electrek. Retrieved January 23, 2022, from https://electrek.co/2021/07/09/nio-plan-open-battery-swap-stations-to-other-electric-automakers/
11. Wayland, M. (2021, August 5). Biden pushes for electric vehicles to make up half of U.S. auto sales by 2030. CNBC. Retrieved February 8, 2022, from https://www.cnbc.com/2021/08/05/biden-pushes-for-evs-to-make-up-40percent-or-more-of-us-auto-sales-by-2030.html#:~:text=Autos-,Biden%20pushes%20for%20electric%20vehicles%20to%20make%20up,U.S.%20auto%20sales%20by%202030&text=President%20Joe%20Biden%20will%20announce,new%20vehicle%20sales%20by%202030.