EXECUTIVE SUMMARY

FUTURE ENERGY FOR MOBILITY

Cost Comparison of Battery Swapping and Fast Charging for Electric Vehicles

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Battery swapping is reemerging as an alternative to fast-charging electric vehicles. While early attempts focused on personally owned vehicles, more recently, the technology has been used to support fleets of electric taxis. In this analysis, we conclude that battery swapping is a competitive solution for supporting fleets. Additionally, we find:

• Frequent and fast charging negatively impacts cycle life, resulting in high battery replacement costs for the fastest charging stations.

• Battery swapping offers the cycle life benefits of slow-charging batteries but faster range addition than even the fastest charging stations.

• China is the most promising region for pioneering battery swapping solutions due to favorable economics, innovative companies, and government policies that are promoting battery swapping.

Executive Summary

Annual equivalent cost
100-vehicle fleet, 10-year lifetime

<table>
<thead>
<tr>
<th>Service Type</th>
<th>U.K.</th>
<th>China</th>
</tr>
</thead>
<tbody>
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<td>Fast charging</td>
<td>$1,000,000</td>
<td>$1,200,000</td>
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<tr>
<td>Fast charging+storage</td>
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<td>Battery swapping</td>
<td>$0</td>
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Fast charging emerged as the winning response to consumer concern over charging time and limited range

Electric vehicle (EV) sales continue to grow, and this also means changes in infrastructure as fueling is replaced by charging. Studies have shown that BEV and PHEV owners charge at home for between 50% and 80% of all charging sessions, but access to fast charging networks is still crucial for nondaily trips that exceed or come close to the range of a vehicle.

Surveys of consumers continue to show that concerns about range, charging speed, and the availability of fast charging stations continue to be front of mind for many consumers. Growing BEV market share means automakers must focus on meeting customer pain points – a point that automakers recognize. Tesla invested heavily in its Supercharger network as a point of differentiation early on, while incumbent automakers are deploying their own networks, such as the Ionity network, to compete.

Surveys of car buyers highlight the same concerns: high prices, poor range, and limitations in charging infrastructure

What improvements make you more likely to purchase a BEV?

Source: Consumer Reports, July 2019
Battery swapping provides an alternative to fast charging stations

Instead of quickly charging the battery, battery swapping solutions aim to physically replace a depleted battery with a charged one. Battery swapping can address two main challenges with fast charging: It slowly charges depleted batteries to minimize grid impact, and it allows for faster addition of range in vehicles.

Most proposed solutions, such as Nio’s solution shown to the right, use robotics to automatically swap the batteries, a process that can be completed in three minutes. Given that the battery pack can weigh up to 1,000 lbs, robotic solutions are required for Nio and many others focused on light-duty vehicle swaps. As the battery is no longer part of the vehicle, Nio’s customers purchase the vehicle and lease the battery pack. Similar to Tesla’s early deployments of its supercharger network, the company has offered free swapping as an incentive for customers. The concept is not an entirely new one; as we show on the next slide, various battery swapping concepts and companies have pursued commercialization of the idea.

Nio’s battery swapping station raises the vehicle and includes a robotic system which removes the old battery and replaces with a new one.

Image credit: Red Dot
Early battery swapping operations failed, but renewed interest is focused on a specific high-value application

Battery swapping, and its primary innovator Better Place, failed a decade ago for three key reasons:

• **Station costs ballooned**: Battery swapping stations, like fast charging, involve high capital costs; Better Place claimed the station costs were roughly $500,000 – although it was later revealed that the real price tag was closer to $2 million. With so few vehicles on the road, not enough swaps were occurring to earn back these high costs.

• **Battery packs were not standardized, and too few compatible vehicles were sold**: Early battery swapping models required automakers to agree on one standardized swappable pack design and use pricing models where customers leased the battery. The only compatible vehicle, the Renault Fluence Z.E., had sold fewer than 1,000 units at the time of Better Place’s bankruptcy in May 2013.

• **Infrastructure needed to span a large geography**: In order to ensure that vehicle owners could freely travel using their vehicles, infrastructure needed to be deployed across entire regions. To make matters worse, the Renault Fluence Z.E.’s range was just 115 miles, meaning this swapping infrastructure needed to be densely deployed.

Today, the renewed focus on battery swapping is aimed mostly at supporting taxi fleets. This is a promising application fit, as it reduces those two of these three barriers: The large fleet usually consists of one vehicle manufacturer and is restricted to operation in a city or other small geography. In this report, we compare the costs of supporting electric taxis with battery swapping and DC fast charging.
Methodology

In order to assess and compare the costs associated with the deployment and regular operations of the current alternatives to support electric mobility, Lux developed a model that considers expected capital expenditure (capex) and operational expenditure (opex) for battery swapping and fast charging installations.

In this case, we use the model to perform a cost analysis of infrastructure supporting an electric fleet of taxis in two different countries – the U.K. and China. We selected the U.K. due to its focus on decarbonizing its taxi and ride-hailing fleets and China because it is the biggest EV market in the world. The model will showcase expected costs in three scenarios – fast EV charging, fast charging with stationary storage support, and battery swapping – in each location.

Our analysis relies on a combination of publicly available information, academic publications, corporate studies, and primary research.
In order to make a fair comparison among all station configurations considering both upfront and recurring operational costs, we use the annual equivalent cost of each station configuration during the lifetime of the project. For simplicity, the upfront cost is annualized over the 10-year project lifetime period, assuming a 0% interest rate and no salvage value.

Without considering battery degradation, two 150 kW chargers is the most attractive option, with all three solutions being very comparable. However, repeated high-power charging results in significant degradation; taking into account battery replacements, 50 kW is the most attractive option. Battery replacements assume batteries charged at 50 kW last 2,000 cycles, batteries charged at 150 kW last 1,000 cycles, and batteries charged at 350 kW last 500 cycles.
Even when there is a higher capex when adding stationary storage, all fast charging station configurations lower their annual equivalent cost compared to the previous scenario without on-site storage.

In all scenarios, the lower-powered 50 kW charging is the lowest-cost option to power fleets of taxis, due primarily to battery replacement costs in faster charging. While this model does not consider lost revenues from time spent charging, 350 kW charging is seven times faster than using a 50 kW charger. With a total cost difference of roughly $200,000 between 50 kW and 350 kW charging, an operator would only need to make up an additional $570 per day across its fleet to make up for the higher operating costs.
SCENARIO #1/#2 – China
Fast charging station with on-site storage

Following the same approach as for the first two scenarios in the U.K., we modeled the economics when adding stationary storage to all fast charging station configurations in China.

We see the same result of all annual equivalent costs decreasing for each station configuration thanks to the support of stationary storage during charging events and removing the demand charge element from the opex side.

When compared to the same scenarios in the U.K., in China we see overall increased annual equivalent costs mainly due to battery replacements.
Using the same fleet of 100 electric taxis, we modeled the economics of installing and operating a fleet supported by battery swapping stations. The results show that the capex related to the vehicles is slightly higher than in the previous two scenarios due to extra batteries required in the network to ensure that a battery is always charged and available. EVs capable of battery swapping can be sold at a lower price, and the battery can be bought separately or leased, though here we assume they are purchased upfront.

On the station side, in China, the swapping station is almost twice the cost of the 150 kW charging station with stationary storage, while in the U.K., the difference in upfront cost is more significant. We assume that swapping stations cost roughly $420,000, while stations in Europe cost roughly $1 million due to differences in engineering, permitting, and construction costs.
Regarding opex, in both geographies, annual operational costs are higher when using battery swapping than in the scenario using fast charging stations coupled with stationary storage to keep a fleet of taxis charged. However, this cost element is lower than any of the other two most attractive alternatives using fast charging stations with 50 kW charging points (with no stationary storage).

For battery swapping stations, the electricity costs are the main element contributing to opex, followed by the maintenance of the vehicles, which uses the same assumption as in the previous two scenarios of 5% of the total vehicle cost annually.

Furthermore, the demand charge component is considerably larger in China, as the stations perform close to double the number of daily swaps that they do in the U.K., needing to have more charged batteries in the station ready to be swapped for the taxis to minimize their idle time.
Comparing all scenarios using the annual equivalent cost calculation, we find that broadly, battery swapping is competitive as a solution for electrifying fleets today. In China, the higher average taxi travel distance means that costs are slightly higher and battery swapping is more competitive in this region than in any other.

For taxis, the primary draw for battery swapping is enabling fast “recharging” times without sacrificing the decrease in cycle life that comes with faster charging. Although costs will vary between regions – and even between cities within each region – battery swapping solutions should be considered in fleet electrification initiatives. Moving forward, as grid congestion from electric vehicles increases and battery swapping companies mature, the swapping vs. charging questions should tip further in favor of swapping.
Stationary storage adds value to fast charging stations

The model results show that integrating stationary storage in fast charging stations lowers the annual equivalent cost by reducing annual opex. However, there are additional benefits to this configuration that impact capex and open up the opportunity for additional revenue generation.

First, stationary storage reduces installation costs by avoiding grid connection upgrades. Fast charging point solution providers like FreeWire Technologies and Kreisel Electric already integrate Li-ion batteries into their fast charging solutions. In addition, EV charging network operators like Ionity and Shell are also reaping the benefits of buffering fast charging with stationary batteries.

Second, the stationary storage component will become an additional source of income for charging infrastructure owners by participating in energy markets, increasing the attractiveness of this type of configuration even more.
China will be the first market where swapping wins

Battery swapping still has to catch up with incumbent EV charging solutions; innovations around battery swapping are further behind in the technology learning curve than those related to fast charging points. Further technology development in combination with the push for a larger installed base of battery swapping stations will help drive costs down.

Current incentive schemes in China actually benefit battery swapping deployments, making them more cost-effective than fast charging alternatives. In addition, swapping infrastructure in the country is being deployed to support both electric taxi fleets and private EV drivers.

Instead of installing charging points all around major Chinese cities to support the growth of electric mobility in the country, China may opt to promote battery swapping stations, as they allow drivers without access to fixed parking to use stations to power their EV within minutes.
Battery replacement costs are a crucial for keeping costs low for any infrastructure. Most charging infrastructure shows roughly equal costs, but factoring in battery replacements due to faster charging makes 50 kW charging the cheapest form of charging.

Battery swapping is most competitive for large fleet sizes. In China, battery swapping is the cheapest and fastest solution for powering electric vehicles in large fleets of more than 10,000 vehicles, while in Europe, the costs are roughly equal.

China has cemented its position as the leader in battery swapping deployments and will remain the most promising region for the technology. Due to a combination of favorable economics, local companies that have commercialized the technology, and favorable government policies, clients should closely watch activity in the region as a leading indicator of adoption elsewhere.