A Techno-Economic Analysis of BEV Service Providers Offering Battery Swapping Services

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Sponsored by DOE VTP
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Motivation

• Battery electric vehicles (BEVs) could significantly reduce the nation’s gasoline consumption and greenhouse gas emissions rates.

• However, both the upfront cost and the limited range of the vehicle are perceived to be deterrents to the widespread adoption of BEVs.

• A service provider approach to marketing BEVs, coupled with a battery swapping infrastructure deployment could address both issues and accelerate BEV adoption, but does it make financial sense to the consumer?
Outline

• Customer Selection
• Service Usage Statistics
• Service Plan Fees
• Driver Economics
Customer Selection: Unachievable Travel

• Our studies have shown that how a driver completes travel not achievable with a BEV (e.g., day trips longer than the range of the vehicle) strongly impacts economics.

• If you can complete unachievable travel at low marginal cost (e.g. use another CV owned by the household), battery swapping is unlikely to be cost-effective.

• However if unachievable travel is expensive (e.g. a rental car is required), then battery swapping may be an attractive option. Thus we restrict our study to this scenario.
Customer Selection: Drive Pattern Data

- Not all drivers are well suited to a battery swapping service plan, and no battery swapping service provider would target the entirety of the vehicle market.
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Customer Selection: Drive Patterns

• We down-select 100 drive patterns (~25% of the complete TCS set) that show the best potential cost effectiveness relative to directly-owned conventional vehicle (CV) and BEV alternatives using a simplified TCO analysis.

• We find that annual VMT is the single most important factor driving our down-selection.
Service Usage Statistics: Approach

• To calculate service plan fees, we need to know infrastructure requirements and operating expenses.

• Approach: Apply the Battery Ownership Model (BOM) to calculate electricity usage, battery swapping frequency, battery life, and vehicle utility factor for each combination of 100 drive patterns, three vehicle ranges, three maximum battery SOCs, and two fast charge wear factors.

  – Note we apply a limit of four battery swaps per day (max) to account for temporal and spatial restriction on swapping availability, as well as a driver’s willingness to change behavior.
## Service Usage Statistics: Results

<table>
<thead>
<tr>
<th>Range</th>
<th>Max SOC</th>
<th>Fast Charge Wear Factor</th>
<th>Battery Life (yrs)</th>
<th>Annual Electricity (kWh)</th>
<th>Swaps per Year (No.)</th>
<th>Utility Factor</th>
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- **BEV50**: high battery swapping frequency, battery life sensitive to fast charge effects, good utility factor
- **BEV100**: low battery swapping frequency, negligible sensitivity to fast charge effects, utility factor approaching 100%.
Service Plan Fee: Approach

- Input service usage statistics.

- Calculate swap spot infrastructure requirements.
  - Utilization rate (hrs/day) drives number of customers per swap spot (1.2 hrs/day for typical U.S. gas pump).
  - Max time between swaps (minutes) drives number of chargers and batteries at swap spots, and determines customer wait time.

- Account for all swap spot infrastructure, battery, home charger, electricity costs, and operating expenses.

- Calculate service plan fee using a detailed business model to meet return-on-equity (ROE) requirement.
  - Build infrastructure in year zero for 10,000 subscribers using 50/50 equity/debt financing.
  - Remaining working capital following all expenses, taxes, and debt payments is applied to build new infrastructure each year, thereby determining increase in subscribers.
  - Service plan fee is calculated such that the value of the company at year 15 is equal to the initial equity investment had it grown at the prescribed ROE.
Battery cost and cost of financing are the two highest impact factors.
Swap spot service variables combine to have a large impact too.
Fast charge wear factor has a negligible impact.
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Service Plan Fee: Cost Breakdown

High Service, High Cost Battery Swapping

- Batteries are a major cost component in nearly every scenario.

Low Service, Low Cost Battery Swapping

- Swap spot infrastructure costs can vary from insignificant to the largest single cost element.
Individual Driver Economics

(a) Fraction choosing SP-BEV over DO-BEV75

(b) Fraction choosing SP-BEV over DO-CV

- Low Cost, Low Service Swap Spots
- High Cost, High Service Swap Spots

<table>
<thead>
<tr>
<th>Battery Type</th>
<th>$125/kWh Batteries</th>
<th>$300/kWh Batteries</th>
<th>$475/kWh Batteries</th>
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<tr>
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Remaining Questions

- How big is the applicable high mileage, high cost of unachievable VMT market?
- How much of a premium is this market willing to pay over a CV?
- What level of convenience will be necessary?
- How will temporal and spatial factors impact necessary infrastructure deployments?
- What other consumer-choice factors will have a strong impact on adoption of a battery swapping service plan?

Presumably, the answer to many or all of these questions is not supportive of a battery swapping service in the US.

http://www.bizjournals.com/sanfrancisco/blog/2013/02/betterplace-will-cease-us-operations.html?page=all
Conclusions

• It is unlikely that a battery swapping service plan will be more cost-effective than ownership of a conventional vehicle.

• A battery swapping service plan may be a more cost-effective solution than a directly owned BEV for some single-vehicle, high-mileage consumers.

• However, other factors not considered in this analysis could decrease the viability of such a service.
• Aggression variation between drivers can increase fuel consumption by more than 50% or decrease it by more than 20% from average.

• The normalized fuel consumption deviation from average as a function of population percentile was found to be largely insensitive to powertrain. – I.e., the ability of aggression to impact relative fuel consumption is similar for CVs, HEVs, PHEVs, and BEVs.

• However, the traits of ideal driving behavior is a function of powertrain. – In CVs, kinetic losses dominate rolling resistance and aerodynamic losses.

• In xEVs with regenerative braking, rolling resistance and aerodynamic losses dominate.

• The relation of fuel consumption predicted from real-world drive data to that predicted by the industry-standard HWFET, UDDS, LA92, and US06 drive cycles was not consistent across powertrains, and varied broadly from the mean, median, and mode of real-world driving.

• A drive cycle synthesized by NREL's DRIVE tool accurately and consistently reproduces average real-world for multiple powertrains within 1%, and can be used to calculate the fuel consumption effects of varying levels of driver aggression.