Infrastructure, Components and System Level Testing and Analysis of Electric Vehicles

Cooperative Research and Development Final Report

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In accordance with Requirements set forth in Article XI.A(3) of the CRADA document, this document is the final CRADA report, including a list of Subject Inventions, to be forwarded to the Office of Science and Technical Information as part of the commitment to the public to demonstrate results of federally funded research.

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CRADA Title: Infrastructure, Components and System Level Testing and Analysis of Electric Vehicles

Parties to the Agreement: A Better Place

Joint Work Statement Funding Table showing DOE commitment:

Estimated Costs	NREL Shared Resources
Year 1	$ 300,000.00
Year 2	$ 300,000.00
Year 3	$ 300,000.00
TOTALS	$ 900,000.00

Abstract of CRADA work:

Battery technology is critical for the development of innovative electric vehicle networks, which can enhance transportation sustainability and reduce dependence on petroleum. This cooperative research proposed by Better Place and NREL will focus on predicting the life-cycle economics of batteries, characterizing battery technologies under various operating and usage conditions, and designing optimal usage profiles for battery recharging and use.

Summary of Research Results:

We analyzed the economics of battery electric vehicles (BEVs) operated under a service plan where battery swapping is available to extend vehicle range. Our evaluation process followed four steps: (1) identifying drive patterns best suited to a battery swapping service plan, (2) modeling service usage statistics for the selected drive patterns, (3) calculating the cost of service plan options given these statistics, and (4) evaluating the economics of individual drivers under realistically priced service plans (SPs). For comparison, we have also calculated the total cost of ownership (TCO) of both a BEV75 and a conventional vehicle (CV) operated under a conventional direct-ownership (DO) scenario. A high fidelity battery degradation model has been employed throughout to forecast battery wear, its effect on vehicle range, and required battery replacements. Real world drive patterns from the Travel Choices Study (TCS) project have been utilized to support the calculation of realistic battery usage, the frequency of battery swapping events, and the fraction of achievable vehicle miles travelled (VMT). The cost of unachievable VMT has been accounted for based on the cost of popular car share programs, making our results most generally applicable to drivers without access to an alternative lower cost, range-unlimited mode of transportation (e.g. a second non-BEV car owned by or freely available to said driver). Further, a detailed accounting of the economics of a battery swapping service provider, including consideration of the amount of required infrastructure, financing of capital expenditures, taxes, depreciation, etc., has been applied to calculate the fee charged to the consumer for battery swapping service plans.

As should be expected, we find that drive patterns with high annual VMT are generally best suited to range extension (e.g., battery-swapping) SPs. The range extension infrastructure utilization to be expected from such drive patterns varies considerably – primarily as a function of the range of the BEV, where shorter BEV ranges encourage a higher frequency of range extension events. For all vehicle ranges, however, the achievable utility factor is high when range extension infrastructure is adequately placed and up to four range extensions per day are allowed: spanning from a low of 85% at 50 miles to a high of 94% at 100 miles.

In calculating the monthly service fee of a battery-swapping SP, we find that the high level of capital expenditures involved in the service provider's business model makes the cost of financing very important. The large capital costs are generally best attributed to the cost of batteries (as opposed to infrastructure, electricity, charge points, and other general and administrative costs). However, if the cost of individual battery swap spots approaches or exceeds the high end of our assumptions, and geographic and/or customer service requirements demand a high number of swap spot deployments per customer, infrastructure costs can compete with and even exceed those of batteries.

In applying the calculated service fee to individual driver economics where the cost of unachievable VMT is high, our simulations show that the economic efficiency of a battery swapping SP-BEV is often challenged by the cost of batteries, infrastructure, and financing. Under our assumed cost of gasoline, tax structure, and absence of purchase incentives, we find that these factors generally make the TCO of the SP-BEV more expensive than that of a DO-CV. Only when battery costs reach the DOE's most aggressive target ($125/kWh) and infrastructure costs achieve our lowest assumed values do we see significant numbers of drive patterns benefiting economically over the CV option.

However, where the cost of unachievable VMT is high, we do find the SP-BEV to be a more cost-effective approach to electrifying travel for a significant number of drive patterns than a DO-BEV75 under a broad range of scenarios for the cost of batteries and infrastructure. There is also additional potential for service providers to improve the relative value of BEVs via multi-tiered fee and service strategies, optimal allocation and down-cycling of aged batteries, and revenue generation via vehicle-to-grid services (which, we note, a service provider is well positioned to optimize).This, along with several assumptions and simplifications made in this analysis, encourage further study of battery-swapping service plans. Along with these aforementioned avenues for value improvement, such efforts must also address several aspects of batter-swapping SP business models that could detract value, including accounting for business start-up costs (that could be significant over a period of several years or more before generating any revenue), marketing, engineering, and management staff expenses, the increase in cost to the vehicle glider for a swappable battery, and increased infrastructure utilization due to the geographic and temporal distribution of subscriber battery-swapping needs and other unaccounted-for driver behavior (e.g., range anxiety). Further, the concurrence of both a high cost of unachievable VMT and high annual VMT, which may decrease the potential customer base, should be considered. And, finally, other elements that are more difficult to quantify economically – such as customer willingness to subscribe to a service contract for battery service while owning a vehicle without a battery, to increase stopping frequency on long travel days, etc. – must be addressed as well.

Subject Inventions Listing: N/A

Report Date: 09 April 2013 **Responsible Technical Contact at Alliance/NREL**: Jeremy Neubauer

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