Journal of Power Sources 271 (2014) 614–621

Contents lists available at ScienceDirect

Journal of Power Sources

journal homepage: www.elsevier.com/locate/jpowsour

Updating United States Advanced Battery Consortium and Department of Energy battery technology targets for battery electric vehicles

Jeremy Neubauer [a, *], Ahmad Pesaran [a], Chulheung Bae [b], Ron Elder [c], Brian Cunningham [d]

[a] National Renewable Energy Laboratory, 1617 Cole Blvd, Golden, CO 80401, USA
[b] Ford Motor Company, 2101 Village Rd, Dearborn, MI 48121, USA
[c] Chrysler Group LLC, 800 Chrysler Drive, Auburn Hills, MI 48326, USA
[d] U.S. Department of Energy, 1000 Independence Ave., Washington, DC 20585, USA

HIGHLIGHTS

- Joint effort of USABC and DOE.
- Technology agnostic approach to identify BEV battery performance and cost targets.
- Resultant targets will drive future battery development.

ARTICLE INFO

Article history:
Received 1 April 2014
Accepted 9 June 2014
Available online 19 June 2014

Keywords:
United States Advanced Battery Consortium
Battery
BEV
Performance target

ABSTRACT

Battery electric vehicles (BEVs) offer significant potential to reduce the nation's consumption of petroleum based products and the production of greenhouse gases however, their widespread adoption is limited largely by the cost and performance limitations of modern batteries. With recent growth in efforts to accelerate BEV adoption (e.g. the Department of Energy's (DOE) EV Everywhere Grand Challenge) and the age of existing BEV battery technology targets, there is sufficient motivation to re-evaluate the industry's technology targets for battery performance and cost. Herein we document the analysis process that supported the selection of the United States Advanced Battery Consortium's (USABC) updated BEV battery technology targets. Our technology agnostic approach identifies the necessary battery performance characteristics that will enable the vehicle level performance required for a commercially successful, mass market full BEV, as guided by the workgroup's OEM members. The result is an aggressive target, implying that batteries need to advance considerably before BEVs can be both cost and performance competitive with existing petroleum powered vehicles.

1. Introduction

Battery electric vehicles (BEVs) offer significant potential to reduce the nation's consumption of gasoline and production of greenhouse gases. However, one large impediment to the commercial success and proliferation of these vehicles is the cost and performance limitations of current battery technology. BEVs on the market today come with a significant cost premium relative to their conventionally powered counterparts, even after significant federal and state purchase incentives are included. In addition, the range of the vehicle is typically restricted by limited battery energy to ~100 miles under optimum driving conditions. That value can fall considerably in the presence of high auxiliary loads, aggressive driving, extremely cold temperatures, or later in life as the battery ages. Furthermore, when a BEV is based upon a platform designed for a conventional powertrain, the volume displacement of the battery necessary to achieve this limited range results in a reduction in the available passenger or cargo volume. Additionally, as it may be necessary to modify the vehicle chassis to support the large mass of the batteries due to their low specific energy, which adds additional cost to the BEV equivalent.

Improvements in battery technology have the capacity to resolve all of these issues. Accordingly, the Department of Energy (DOE), the United States Advanced Battery Consortium (USABC), and others are directing significant resources towards the development of batteries for BEVs. For example, the DOE has initiated its EV Everywhere Grand Challenge [1] to accelerate BEV

---

* Corresponding author. Tel.: +1 720 989 1919.
E-mail addresses: Jeremy.neubauer@nrel.gov, jeremy.s.neubauer@gmail.com (J. Neubauer).

http://dx.doi.org/10.1016/j.jpowsour.2014.06.043

advancement, with a heavy focus on advanced battery technology. In partnership with DOE, the USABC also sets its own battery technology targets to drive developments in the industry. However, as of 2012, the USABC's working BEV battery technology targets were more than 20 years old [2], and documentation providing insight into their development was exceptionally scarce. In light of significant developments in the automotive markets since the last target setting activity and recently increased efforts to deploy BEVs, there is motivation to develop an updated set of BEV battery technology targets.

Consequently, in 2012, the DOE and USABC jointly set out to create a new set of battery technology targets for BEVs. It was desired that the targets be designed to deliver a BEV capable of broad market success if achieved. To achieve this end, the resources of the National Renewable Energy Laboratory (NREL) were leveraged to supply detailed technical analysis, guided by the insight of the USABC's vehicle OEM members on consumer requirements and future vehicle and battery technology trends. Herein, we document this process of updating these battery targets as well as communicate our results.

2. USABC target setting analysis

The objective of this analysis is to identify battery available energy, mass, volume, cost, discharge power, and charge power requirements that will enable broad commercial success of BEVs if the requirements are achieved. Our approach to achieving this objective begins by first specifying the relevant vehicular level performance requirements necessary for commercial success; namely, acceleration and range. Next, we select a vehicle platform with broad market appeal and define its mass and aerodynamic properties using forecasted values for our timeframe of interest. At this point we calculate the required energy and power to meet our range and acceleration targets, then analyze charge and discharge power requirements using vehicle simulation software. Finally, we calculate available battery mass and volume, followed by allowable battery cost to provide cost-parity with a comparable conventionally powered vehicle. All of these steps are detailed in the sections that follow.

2.1. *Defining vehicle performance*

Two factors of BEV performance are relevant to this study: acceleration and range. These two metrics will have direct impact on the required battery energy and power requirements, and indirectly affect battery mass and cost (considering the mass and cost of the necessary motor and power electronics).

To define an acceleration requirement, we first surveyed the OEMs' preference. This yielded a 9 s 0–60 mph time as an acceptable level of performance. We then simulated a BEV in ADVISOR [3] with this level of performance to 2154 real-world vehicle records [4]. We found that this vehicle was capable of achieving the vehicle speed histories within 1 mph 97.6% of the time across all records. Based on this result, we elected to proceed with the 9 s 0–60 mph acceleration time on the basis that such a vehicle is capable of meeting the dynamic requirements of many drivers.

Defining necessary vehicle range is a more difficult task. If a comprehensive data set on consumer driving habits was available, a complex techno-economic analysis could provide insight into the selection of a cost-optimal range. Such a data set must provide distance and timing information of each trip taken by an individual driver to enable the calculation of vehicle utility, while spanning no less than 365 continuous days to account for seasonal effects. A large number of diverse drivers must also be addressed, to account for variation in driving habits with geography, occupation, age, sex, and other relevant demographics. Further, as vehicle purchase decisions are not generally made on a purely economic basis, consumer choice factors must also be brought into play, further complicating identification of an optimal range for our BEV.

As the necessary data and tools to make an optimal range selection were not available to the authors (nor do they exist, to our knowledge), a more qualitative approach was necessary. We first narrowed our scope to a minimum range of 100 miles, on the justification that our target must improve upon the current state of the art; and, a maximum range of 300 miles, anticipating that such a large range would lead to overly ambitious targets. Second, we looked at national fleet utility factors using the 2009 National Household Travel Survey data [5] assuming a once-per-day charging algorithm and that there is always sufficient time to completely recharge the battery. As seen in Figs. 1 and 2, this data set projects that a vehicle with our minimum range of 100 miles would cover 94% of all travel days and 68% of all miles traveled if deployed nationally. Note that increases in range offer a diminishing increase in fleet utility. For example, increasing range from 100 to 200 miles increases coverage by 5% of travel days and 14% of miles; while increasing range from 200 to 300 miles increases coverage by less than 1% of travel days and 4% of miles.

Note that these are fleet utility factors (based on cross sectional drive distance distributions) rather than individual driver or vehicle utility factors (based on longitudinal drive distance distributions). Accordingly, some drivers or vehicles may have very few of their driving needs met with a range of 200 miles, while others may have all of their needs met (and indeed considerably underutilize the vehicle's full capability).

To provide some insight into the fraction of drivers that would achieve a high utility from such a vehicle, we applied a longitudinal data set of 317 vehicles from the Puget Sound Regional Council's Transportation Choices Study (TCS) [6]. This subset of the larger TCS sample was selected for high data quality over a continuous 365 day period. We resolved the data to a sequence of parked-at-home events and home-to-home driving tours. We then calculated 365 day battery state of charge (SOC) and vehicle miles traveled (VMT) histories for each of the 317 vehicles by applying the following two assumptions to this data: (1) the vehicle is charged with a level 2 charger every time the vehicle is parked at home, and (2) if the SOC of the battery is not sufficient to complete a home-to-home tour at the original time of departure, the BEV is not used for that tour. The miles-based utility factor for each vehicle can then be

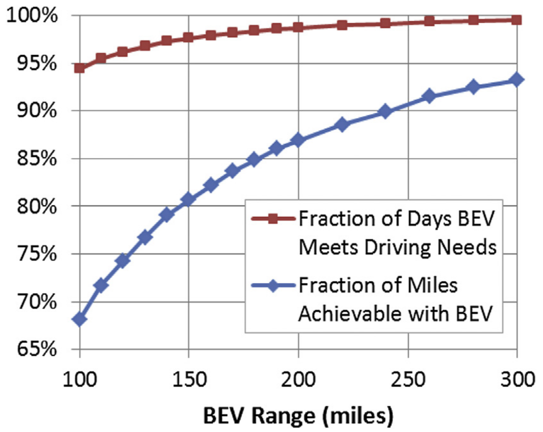

Fig. 1. Days- and miles-based fleet utility factors for BEVs as a function of range based upon 2009 NHTS data.