

# Developing a Utility Factor for Battery Electric Vehicles

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## ABSTRACT

As new advanced-technology vehicles are becoming more mainstream, analysts are studying their potential impact on petroleum use, carbon emissions, and smog emissions. Determining the potential impacts of widespread adoption requires testing and careful analysis. PHEVs possess unique operational characteristics that require evaluation in terms of actual in-use driving habits. SAE J2841, "Utility Factor Definitions for Plug-In Hybrid Electric Vehicles Using 2001 U.S. DOT National Household Travel Survey Data," published by SAE in 2009 with a revision in 2010, is a guide to using DOT's National Household Travel Survey (NHTS) data to estimate the relative split between driving in charge-depleting (CD) mode and charge-sustaining (CS) mode for a particular PHEV with a given CD range. Without this method, direct comparisons of the merits of various vehicle designs (e.g., efficiency and battery size) cannot be made among PHEVs, or between PHEVs and other technologies.

The dedicated battery electric vehicle (BEV) is now becoming a viable alternative to conventional vehicles and other advanced vehicles (like HEVs and PHEVs). However, a shortcoming persists in current comparisons between BEVs and other vehicles. The BEV cannot satisfy all individual driving needs and most likely will be used alongside other household vehicles (which use petroleum fuel). To properly assess impacts of widespread BEV adoption, a "BEV Utility Factor" will be necessary. Using the most current NHTS data with individual trip data, several charging and vehicle-use scenarios are presented to bookend the expected utility of electric drive capability at any given BEV range. This analysis reveals that a real-world 75-mile-range BEV with a safety reserve of 10 miles has virtually the same electric drive utility as a PHEV with a 38-mile electric-only (CD) range.

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## INTRODUCTION

### Utility Factors for PHEVs

PHEVs are essentially HEVs with added battery capacity and an operational mode designed specifically for charge-depleting (CD) operation. The term "Utility Factor" (UF) was first associated with PHEVs in the original SAE J1711 of 1999 [1,2] in order to handle the weighting between the CD and CS modes. For any given drive cycle (or procedure), there will be an associated CD range. UFs apply to both PHEVs that deplete using only the battery (extended-range electric vehicles [EREVs]) and PHEVs that require an engine to assist in driving (blended PHEVs).

The following example will illustrate the significance of using the UF method to draw comparisons among PHEVs with varying operational capabilities. In [Figure 1](#), four different PHEVs are defined with varying fuel economies and CD ranges. Predicting which vehicle will use the smallest amount of fuel depends upon the combination of fuel

economy in depleting and sustaining modes and the depleting range.

Compared with Case A, Case B has a much shorter range, but runs CD in all-electric mode. With the same CD fuel economy as Case A, Case C has a shorter range but has a higher CS fuel economy. Without the UF method, competing aspects of each design make it impossible to predict which vehicle may save the most fuel when driven by a large number of households in the U.S.

The results of the UF analysis are shown in [Table 1](#) below. The case with the lowest fuel-only consumption is Case B. Case A uses the most fuel. CD fuel consumption, range and CS fuel consumption all play important roles in determining the potential of a particular PHEV design to save fuel.

Analysis involving the comparisons of various PHEVs with other vehicles is best done using the UF approach. The literature [3] has firmly established the UF approach (typically using the DOT National Household Transportation Survey [NHTS] [4]) to appropriately account for the CD

mode for any given PHEV design under analysis. However, this established approach has not been extended to BEVs under analysis. The objective of the present work is to calculate a UF suitable for BEVs.

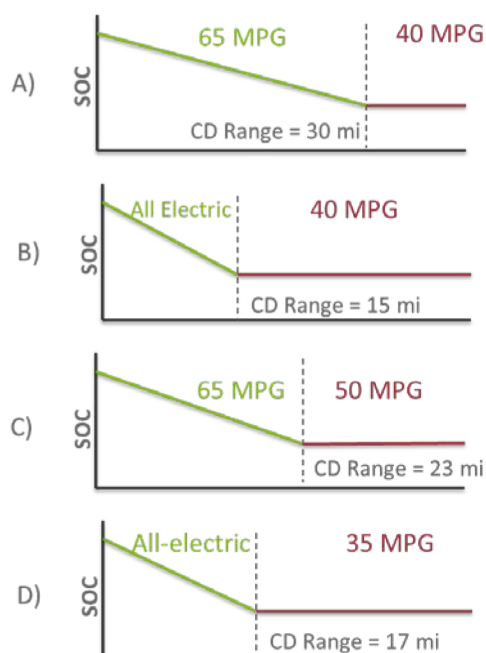


**Figure 1. Illustrating Utility Factor Analysis with Four Hypothetical PHEV Examples**

**Table 1. Fuel Usage of Four PHEV Examples Using Utility Factor Analysis**

| Case | gal/mi<br>CD Mode | gal/mi CS<br>Mode | UF   | 1-UF | UF-<br>Weighted<br>CD gal/mi | UF-<br>Weighted<br>CS gal/mi | Total<br>gal/mi | UF-<br>Weighted<br>MPG |
|------|-------------------|-------------------|------|------|------------------------------|------------------------------|-----------------|------------------------|
| A)   | 0.0154            | 0.0250            | 0.53 | 0.47 | 0.0082                       | 0.0118                       | 0.0199          | 50.2                   |
| B)   | 0.0000            | 0.0250            | 0.32 | 0.68 | 0.0000                       | 0.0170                       | 0.0170          | 58.8                   |
| C)   | 0.0154            | 0.0200            | 0.44 | 0.56 | 0.0068                       | 0.0112                       | 0.0180          | 55.7                   |
| D)   | 0.0000            | 0.0286            | 0.35 | 0.65 | 0.0000                       | 0.0186                       | 0.0186          | 53.8                   |

## APPROACH

### Defining UFs for PHEVs and BEVs

Consider the raw data input used in the creation of a UF; here we use the 2009 NHTS data on daily vehicle miles traveled. Figure 2 shows the data from the nearly 125,000 records, in an ordered set (unweighted). For the sake of argument here, a PHEV with a 75-mile range will drive all miles under the line in Figure 2, defined as subset A. This analysis assumes a fully charged PHEV at the beginning of each day and thus a single charging event for every driving day in the dataset. The miles above the line, defined as subset B, are driven in CS mode. The UF for 75 miles is calculated in a straightforward manner as A (CD miles) divided by A + B (total miles).

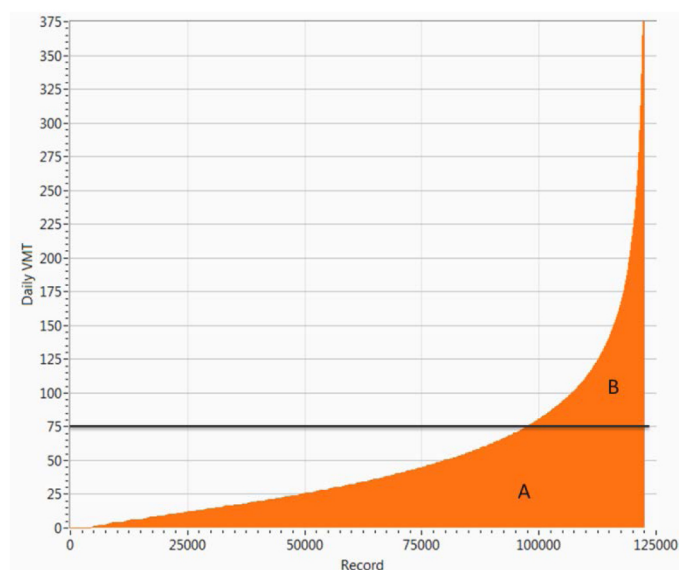


**Figure 2. UF Analysis for a PHEV Using 2009 NHTS Data (Represented in an Ordered Set)**

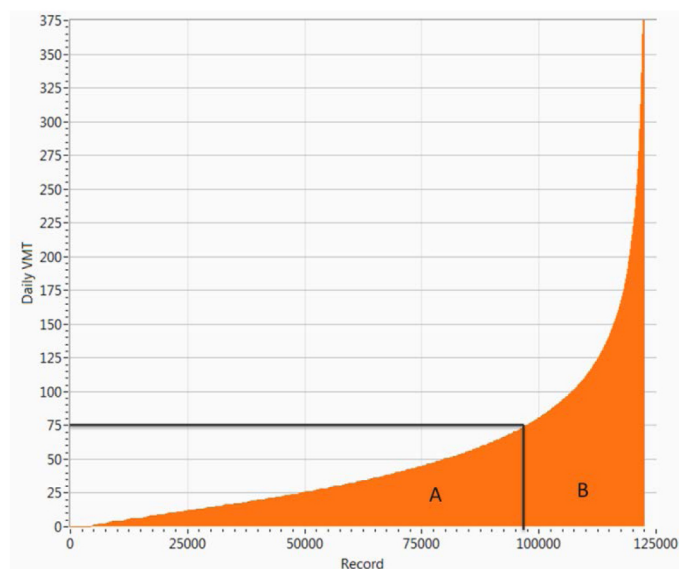


**Figure 3. UF Analysis for a BEV Using 2009 NHTS Data (Represented in an Ordered Set)**

Considering the same data in the context of BEV usage, one asks a very similar question: what fraction of the nation's daily driving can be satisfied by a BEV with a given range? In Figure 3, the line is drawn vertically: all the miles driven in subset A can be driven by the BEV, but subset B is more problematic for the BEV. This subset contains all the days in which the driving requirements cannot be totally satisfied by a BEV and an alternative vehicle must substitute for the BEV for some fraction of the trips. On the days when the driving miles are all in one long round trip, 100% of the day's miles are non-electric. For other days in the survey, with a mix of

short and long trips, the short trips can be driven by the BEV, allowing some fraction of that day's miles to be electric.

In subset B, each day must be analyzed to find the number of miles in that day that can possibly be driven by the BEV and the number of miles that cannot be driven by the BEV, based upon the individual trips taken. This is the BEV UF approach.

The BEV is at a disadvantage compared to PHEVs with regard to achieving high UF numbers for a given range. For the entire dataset (every daily driving day), the initial miles driven by a PHEV are always in the CD mode. Given that BEVs typically have a longer range than PHEVs, a comparison between available PHEVs and BEVs using the UF approach may be very interesting (more on this later in the paper).

## Data Preparation

The first step is to take the individual trip records for a given vehicle in a household and combine each string of trips that originate and end at home. The resulting new dataset is a record of all round trips in a single day for each vehicle. The reason for this step is that it is assumed that each decision to use either the BEV or its household alternative for the next trip will be made each time a vehicle returns home.

A second dataset includes the associated weighting (all the data have weighting values to match the dataset to the entire U.S. driving fleet). A third dataset used is the dwell time for each stop at home during the day. These three (3) datasets will be needed to complete the analysis.

## Baseline BEV UF Approach

The UF for a BEV with a given range represents all the round-trip miles that could fit within the daily range divided by the total miles of all trips in the dataset. UF calculations are performed for each BEV range. Here we will calculate the UF from 1 to 300 miles.

The first approach is a baseline approach, where the computer code iterates through all the individual round trips and checks to see if each falls within the BEV range: if it does, then the trip miles are placed in the BEV set. The code then subtracts the round-trip distance from the existing range and moves on to the next round trip in that day, repeating the same comparison. The total miles of any trip that exceeds the remaining range cannot be counted as electric. The code is essentially a simulation of BEV use for every given BEV range.

## Opportunity Charging

It is generally recognized that "opportunity charging" can, on average, increase electric-miles utilization. One approach is to assume all drivers immediately reattach the charge cable to the vehicle every time it returns home. The dwell-time dataset tells us how long the vehicle is regaining vehicle range during the day from at-home charging. Two charge rates were considered: 3.3 kW (0.17 mile/minute) and 6.6 kW (0.34 mile/minute). Charging was only assumed to occur at home (at-work charging was not considered). Because all at-

home dwell time was used for charging, this represents a limit case investigated to see how much benefit is found in at-home opportunity charging.

## Rearranging Trips

Another method finds higher BEV utilization based upon the possibility that the driver could intelligently arrange trips to get more electric driving miles in a day compared to the sequential comparison approach in the baseline method. Short of solving for the optimum combination of EV trips for each household every day, the approach taken here employed trip sorting.

The first attempt at this approach was to sort a given day's round trips in order of small to large before sending them to the comparator code. Intuition failed the author because this approach yielded a UF that was lower (worse) than the baseline approach. Indeed, the number of trips in electric mode increased but the total EV miles decreased.

Then every given day's round trips were fed into the code in reverse order (large to small). This resulted in a slight improvement in EV mile fraction. The reason is that the chance for a smaller round trip to fit within the range later in the day was increased. This approach shows that there is some sensitivity to the driver's decisions on which trips to take with the BEV, but this difference is very small.

## RESULTS

Only by completing the BEV UF analysis can one determine "how electric" a given electric vehicle can be. The first result worth discussing is at a range of 300 miles. The U.S. Department of Energy (DOE) is actively engaged in an initiative to develop the technology for 300-mile electric vehicles with equivalent costs and utility to today's conventional vehicles ("EV Everywhere" Grand Challenge [5]). At 300 miles, the UF values for all the approaches analyzed converge to roughly 0.96. This is indeed a high utility for a BEV with a real-world 300-mile range.

A real-world range of 75 miles is a good representation of many BEVs currently entering the market. The baseline BEV UF approach calculates an electric utility at a 75-mile range of 0.681 (i.e., 68.1% of household miles driven by the electric vehicle). Using the more nearly optimal sorted-trip arrangement, the UF increased slightly to 0.690. And in the limit case, where every vehicle is charged every minute it is parked at home, the UF increases to 0.719 or 0.727, depending upon whether the BEV charges at 3.3 kW or 6.6 kW.

Shifting upscale in the BEV market to more expensive vehicles with much larger-capacity batteries, the baseline UF for a BEV with a 265-mile range is 0.951.

Figure 4 shows BEV UF curves generated for the baseline and trip-sorted UF from zero to 150 miles to illustrate the slim differences in results.