

Design of an On-Road PHEV Fuel Economy Testing Methodology with Built-In Utility Factor Distance Weighting

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ABSTRACT

As vehicle technology progresses to new levels of sophistication, so too, vehicle test methods must evolve. This is true for analytical testing in a laboratory and for on-road vehicle testing. Every year since 1993, the U.S. Department of Energy (DOE) and original equipment manufacturer (OEM) sponsors have organized a series of competitions featuring advanced hybrid electric vehicle (HEV) technology to develop and promote DOE goals in fuel savings and alternative fuel usage. The competition has evolved over many years and has included many alternative fuels feeding the prime mover (including hydrogen fuel cells). EcoCAR turned its focus to plug-in hybrid electric vehicles (PHEVs) and it was quickly realized that to keep using on-road testing methods to evaluate fuel and electricity consumption, a new method needed to be developed that would properly weight depleting operation with the sustaining operation, using the established **Utility Factor** (UF) method. A new approach using three separate trips was devised for the on-road emissions and energy consumption event that matches the **Fleet UF** found in SAE J2841. This paper explains the method and shows the remarkable fit from the three-trip approach compared to the actual UF curve which was constructed using a data set of over 30,000 vehicle-days of travel.

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INTRODUCTION

The U.S. Department of Energy (DOE) has been organizing a number of advanced vehicle technology competitions (AVTC) since 1988. The competitions all share the same fundamental objectives-to develop and demonstrate new advanced vehicle technology and alternative fuels-by building prototype vehicles for competitions in design judging, dynamometer testing, and on-road testing. Annually, since 1993, there have been competitions featuring hybrid electric vehicles (HEVs) as the primary focus of fuel savings technology, with many alternative fuels feeding the prime mover (including hydrogen fuel cells). In [Table 1](#) the technology progression is listed that started with a focus on plug-in hybrid electric vehicles (PHEVs), then shifted to charge-sustaining hybrid electric vehicles (HEVs), but now has shifted back to PHEVs. Emissions and fuel economy scoring were taken from dynamometer testing methods based upon state-of-the-art methods at the time. Since 2006, with the Challenge X competition, all the energy consumption and emissions events were moved from dynamometer testing to an on-road event including emissions which are collected using portable emissions measurement equipment.

Performing testing on-road has several key advantages over dynamometer testing in a competition setting. One is that in dynamometer testing, modifications to the body or chassis to reduce losses require an additional coast down testing event. Also, in on-road testing, several vehicles can be tested at the same time. In the past, the competition had both on-road and dynamometer efficiency events. The objectives of both events can be served by a single on-road event, leaving more time in the competition for other tests.

EcoCAR switched the focus back to PHEVs by awarding points for displaced petroleum using off-board electrical energy. Fairly evaluating PHEVs to compare among the competition vehicles can be quite difficult. Having a wide range of battery capacities and varying rates of depletion confound the question of how much fuel displacement each vehicle offers.

PHEVs have a general operating strategy that assumes each day starts with the battery fully charged, then runs the first portion of daily driving in a depleting mode (full electric or engine and motor blended), until the stored battery energy is depleted. From then on the PHEV acts like a conventional charge-sustaining hybrid. In the laboratory, test methodology includes testing over repeated test cycles until charge-sustaining is observed. The results can be processed to weight



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Table 1. Brief Summary of Past HEV Competitions and Testing Methods

Years	Title	Sponsors	Platforms	Technology Types and Goals	Testing Methods
1993-1995	HEV Challenge	Ford, Chrysler, GM, DOE	Escort Wagon, Ground-Up, Neon	Primarily PHEVs with EV capability	On-Road and Dyno
1996-1999	FutureCar Challenge	Ford, Chrysler, GM, DOE	Taurus, Lumina, Intrepid	Paralleling the PNGV program, conventionals (HEVs), one PHEV	On-Road and Dyno
2000-2001	Future Truck	GM, DOE	Suburban	Primarily HEVs, one PHEV, 2 FCV	On-Road and Dyno
2002-2004	Future Truck	Ford, DOE	Explorer	Primarily HEVs, one PHEV	On-Road and Dyno
2005-2008	Challenge X	GM, DOE	Equinox	Primarily HEVs, one PHEV, 2 FCV	On-Road
2009-2011	EcoCAR	GM, DOE	Vue	Primarily PHEVs, , one HEV, one BEV, 2 FCV	On-Road
2012-2014	EcoCAR 2	GM, DOE	MalibuC	Primarily PHEVs, others TBD	On-Road

each cycle in the series according to the particular utility each test possesses, based upon in-use daily driving distance statistics. In other words, with many short trips representing only the beginning driving cycles, the results of those cycles should be weighted higher than operation after driving much longer distances. This weighting method is called utility factor and it is the subject of SAE document J2841 [1]. For a given charge-depleting distance, the depletion operation has a particular weighting compared to the sustaining operation, according to the utility factor curves in SAE J2841.

Compared to chassis dynamometer testing, there are limits to how much data can be acquired for each vehicle, using on-road testing methods. Both fuel and electricity consumption must be collected with enough distance resolution to make proper weightings. On-dyno fuel consumption is found for each 7 to 10 mile cycle driven. On-road fuel consumption is determined by weighing the fuel tank before and after the event and this is not practical or accurate at short intervals. Electric consumption is taken from the alternating current (AC) recharge energy and proportioning this energy to short segments could require portable laboratory-grade instrumentation on each vehicle running the event. This paper will show a method that facilitates testing fuel and electricity consumption on-road for PHEVs in a competition format (such as EcoCAR and Progressive Automotive X-Prize) with the successful application of utility factor weighting for the charge-depleting operation.

UTILITY FACTOR

Analyzing PHEV results using a **Utility Factor** (UF) was included in the first publication of J1711 in 1999 [2] and revised in 2010 [3]. The reader should be alerted to the fact that the equations used in J1711-1999 are in fact not as accurate as the updated information contained in J2841. There were other sources of data and several utility factors described in J2841, but for the purposes of the EcoCAR Emissions and Energy Consumption event, the **Fleet Utility Factor** (FUF) was used. This is the fraction of total miles driven in the depleting mode at a given charge-depleting range. The data used to generate the Fleet UF were taken from the 2001 National Household Travel Survey (NHTS), a U.S. Department of Transportation (DOT) effort sponsored by the Bureau of Transportation Statistics (BTS) and the Federal Highway Administration (FHWA), to collect data on both long-distance and local travel by the American public [4].

In the source data used to make the Fleet UF there were tens of thousands of records of households driving particular daily distances. This daily driving distance data set is sorted and plotted in [Figure 1](#). This representation shows that the majority of drivers do not drive long distances in any given day; however, there are many total miles driven by a small number of long-distance drivers. The Fleet UF(x) is the mileage-weighted fraction of the first x miles driven by the entire fleet of drivers. Graphically the UF(x), is the fraction of the total area under the line at a given charge-depleting range