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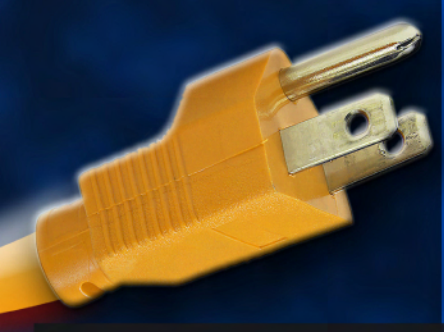


Plug-In Hybrid Electric Vehicles: Determining Their Potential for Reducing U.S. Oil Dependence

Argonne National Laboratory
Anant Vyas, Danilo Santini, Mike Duoba

Electric Power Research Institute
Mark Alexander

Abstract

Estimation of the potential of plug-in hybrid electric vehicles' (PHEVs') ability to reduce U.S. gasoline use is difficult and complex. Although techniques have been proposed to estimate the vehicle kilometers of travel (VKT) that can be electrified, these methods may be inadequate and/or inappropriate for early market introduction circumstances.

Many factors must be considered with respect to the PHEV itself. They include:

1) kWh battery storage capability
2) kWh/km depletion rate of the vehicle
3) liters/km use of gasoline
4) average daily kilometers driven
5) annual share of trips exceeding the battery depletion distance
6) driving schedule(s)
7) charger characteristics and charging rate

Each of these factors is actually a variable, and many interact.

Off the vehicle, considerations include:

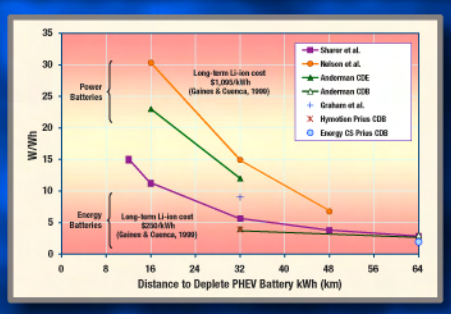
a) primary overnight charging spot [garage, carport, parking garage or lot, on street],
b) availability of primary and secondary charging locations [i.e. dwellings, workplaces, stores, etc.]
c) time of day electric rates
d) seasonal electric rates
e) types of streets and highways typically traversed during most probable trips depleting battery charge [i.e. city, suburban, rural and high vs. low density]
f) cumulative trips per day from charger origin
g) top speeds and peak acceleration rates required to make usual trips

Taking into account PHEV design trade-off possibilities (kW vs. kWh of battery, in particular), useful information relating to these topics has been extracted from the 2001 National Household Travel Survey (NHTS), and the 2005 American Housing Survey (AHS). The focus is on costs per kWh of PHEVs capable of charge depleting (CD) all-electric range (CDE, or AER) vs. those CD in "blended" mode (CDB). Lifetime fuel savings of alternative PHEV operating/utilization strategies are compared to battery cost estimates.

1. 100% Charge-Depleting Mode vs. Blended Charge-Depleting Mode

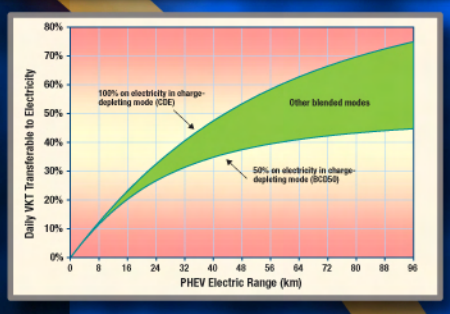
Requiring an ability to run initially on battery power only (charge-depleting electric mode or CDE) will necessitate a large battery pack and a large electric drive. A large battery pack would require substantial space and would reduce either luggage capacity or passenger compartment volume. A PHEV with longer CDE range would require more energy (kWh), but only marginally higher power (kW) resulting in a battery pack that has lower Watt to Watts-hour (W/Wh) ratio. A PHEV designed to allow its engine to assist the electric drive during high power demand would be operating in blended charge-depleting (CDB) mode allowing use of less powerful, more compact electric drive and battery pack.

Prior R&D and field experience indicate sharp reductions in cost of energy ($/kWh) as the W/Wh declines (power batteries vs. energy batteries). Experimental PHEVs (Hymotion, Energy CS) are starting with energy batteries with low W/Wh, operating in CDB mode, taking a long distance to deplete, and limiting kWh and kW in packs to control cost. Theoretical studies show that at a given PHEV range, jumping power capability to accomplish CDE will drive up W/Wh, $/kWh, and PHEV cost. Various studies (see chart) have simulated PHEV and charge-sustaining (CS) HEV battery pack characteristics and tradeoffs.



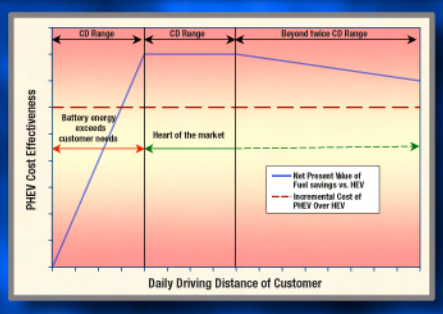
2. Extent of Travel That Can Be Transferred to Electricity

To approximate potential electricity for gasoline displacement potential of PHEVs, SAE International developed a utility factor methodology based on the 1995 National Personal Transportation Survey. An alternative method that computes distance weighted probabilities (DWP) gives slightly higher values for the fraction of travel that can be on electricity. We computed 2001 DWP method values by using data from the 2001 National Household Travel Survey (NHTS) for CDE and CDB50 (50% blended charge-depleting) modes.



3. Attractiveness of PHEVs to Customers

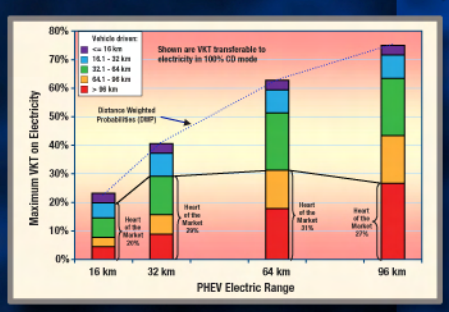
The DWP method assumes everyone buys a PHEV. We examine NHTS data and estimate a much different pattern of marketability. Customers would buy an electric range that is most suited to their typical driving. Ideally the PHEV's CDE range would be selected such that battery energy is effectively utilized. Assuming one overnight charge per day, a customer would benefit the most if his/her daily driving distance takes full benefit of PHEV's electric range. We next consider the likely effect of such customer choice decisions.

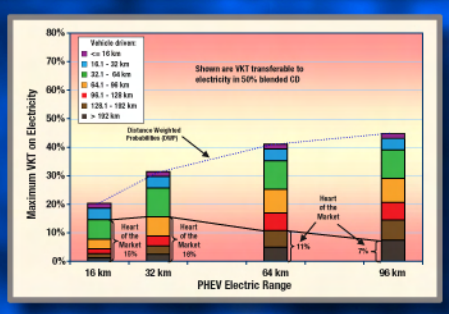


4. Total National Market and Heart of the Market Estimates

The DWP method implies it always is worth increasing PHEV range. Our simple "heart of the market" approach, applied to the 2001 NHTS data, implies that electrification of km benefits rise sharply with increased range up to about 32 km, then either flatten out or drop off.

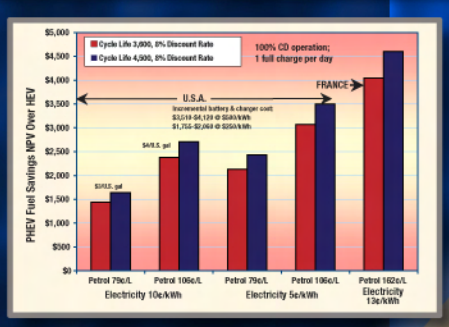
CDE Mode: The 2001 NHTS data were used to develop vehicle kilometer of travel (VKT) shares for various PHEV CDE ranges. As illustrated above, PHEV owners benefit most when their daily driving exceeds PHEV's CD range. The NHTS data showed that if all light duty vehicles were PHEVs, 23% of VKT would potentially be on electricity for PHEV16 (16 km range) operating in CDE mode. However, the heart of the market would consist of 20% VKT only. Although the pack would be too expensive to those traveling less than 16 km/day, eliminating these customers only reduces electric VKT by 3%. However, as PHEV range increases, the percent of lost VKT rises. The chart depicts how the "heart of the market" approach for PHEV16–PHEV96 varies from the DWP method.

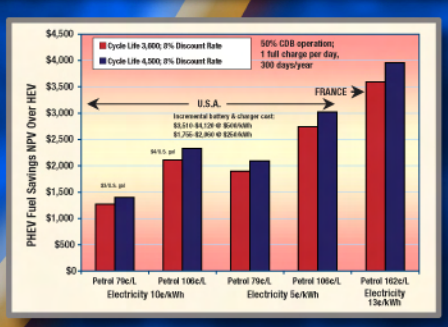




50% CDB Mode: When operating in CDB50 mode, we assumed twice the distance would be required to fully deplete PHEV's battery energy (kWh). This would reduce the size of the "heart of the market" as a PHEV becomes cost effective only for those who travel farther.

5. Illustration of Lifetime Fuel Savings for PHEV32





According to U.S. Department of Transportation's National Highway Traffic Safety Administration (NHTSA), most new vehicle buyers use their vehicles intensively during the first 8 years. Using NHTSA's light-duty vehicle travel schedules together with published charge sustaining HEV fuel efficiency and simulated PHEV fuel efficiency, net present values (NPV) of lifetime fuel savings for PHEV32 were computed. Two illustrations show net present values of potential fuel savings assuming one full charge per day. The first illustration shows NPV for PHEV32 operating in CDE mode and the second illustration shows NPV in CDB50 mode.

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