Benefit Analysis of Plug-In Hybrid Electric Vehicle Technology
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Abstract
This paper presents a potential of plug-in hybrid-electric vehicles (PHEVs) relative to hybrid-electric and conventional vehicles. A benefit analysis is used to show a near-term scenario.

The tradeoffs identified in this paper can provide insight for vehicle manufacturers, policymakers, and the public to identify optimal decisions for PHEV design, policy and use. Given the alignment for economic, environmental and national security objectives, PHEVs on the road will likely be most effective if they focus on adoption of small-capacity PHEVs by urban drivers who can charge frequently.

Keywords
Plug-in hybrid; plug hybrid-electric vehicles; battery, greenhouse gas emission, electric grid

Introduction
A plug-in hybrid-electric vehicle (PHEV) is a hybrid-electric vehicle (HEV) with the ability to recharge its electrochemical energy storage with electricity from an off-board source (such as the electric grid). The vehicle can then drive in a charge-depleting (CD) mode that reduces the system’s state-of-charge (SOC), thereby using electricity to displace liquid fuel that would otherwise have been consumed.

The potential for PHEVs to displace fleet petroleum consumption derives from several factors, driving habits, vehicle size, weather, and tire inflation.

PHEVs are very useful in that they combine the beneficial attributes of HEVs and battery electric vehicles (EVs). Production HEVs achieve high fuel economy, but they are still designed for petroleum fuels and do not enable fuel substitution/flexibility. PHEVs, however, are true fuel-flexible vehicles that can run on petroleum or electrical energy. Battery EVs do not require any petroleum, but are constrained by battery technologies resulting in limited driving ranges, temperature dependence, significant battery costs and lengthy recharging times. PHEVs have a smaller battery which mitigates battery cost and recharging time while the onboard petroleum fuel tank provides the driving range, climate regulations equivalent to conventional and hybrid vehicles. This combination of attributes is building a strong demand for PHEVs, as evidenced by the recently launched plug-in technology.

Modelling PHEV petroleum consumption and cost
Statistics shows that Estonia’s vehicle daily mileage based on the data collected in 2006 is 54 km [1]. Clearly, the majority of daily mileages are relatively short, derived mainly from commuting that starts from point A and ends at the same point. Commonly, one trip covers 27 km. This low daily-mileage characteristic is the reason why PHEVs have a potential to displace a large fraction of petroleum consumption if the charge station infrastructure supports the PHEV and EV distribution. In this modeling we assume that the infrastructure is supporting the PHEV charging, so the car will use only electrical energy. The annual petroleum and electricity consumption was calculated according to the assumption that all vehicles travel 36,950 km per year [2]. The near-term cost of retail gasoline is assumed to be at 16.00 Estonian kroons (EEK) per litre [3]. The cost of retail electricity is constant at 1.47 EEK per kWh [4], based on the retail price, the consumption of electrical energy for an average car is 0.26 KWh/km [5]. It is clear that modeling is sensitive to the cost of gasoline and also to the vehicle retail costs, which are strongly affected by the battery cost assumptions in each scenario. It is also clear that the economy of PHEVs is not promising if gasoline prices remain at current levels and battery costs cannot be improved.

However, it does seem that a compelling business case for plug-in hybrids can be made under a scenario of both higher gasoline prices and projected (lower) battery costs, at least from the perspective of the simple consumer economic comparison presented here. Despite the uncertainty of PHEV economics, there are other factors that may justify the incremental PHEV cost. Examples include the following: tax incentives; reductions in petroleum use, air pollution, and greenhouse emissions; national energy security; reduced maintenance; fewer fill-ups at the gas station; convenience of home recharging; improved acceleration from high-torque electric motors; a green image; opportunities to provide emergency backup power in the home; and the potential for vehicle-to-grid applications. Alternative business models, such as battery leasing, also deserve further consideration since they might help to mitigate the daunting incremental vehicle cost and encourage PHEV buyers to focus on the potential for long-term cost savings.

Modeling values are shown in Table 1.
Table 1. Modelling values

<table>
<thead>
<tr>
<th>Type</th>
<th>Vehicle</th>
<th>Fuel</th>
<th>Cost EEK/km</th>
<th>Retail cost [6] EEK</th>
</tr>
</thead>
<tbody>
<tr>
<td>CV</td>
<td>Toyota Corolla</td>
<td>gasoline</td>
<td>1.6</td>
<td>259,000</td>
</tr>
<tr>
<td>HEV, PHEV EV,</td>
<td>Toyota Prius HEV</td>
<td>gasoline</td>
<td>0.7</td>
<td>399,000</td>
</tr>
<tr>
<td>PHEV-4kwh*</td>
<td>gasoline (reserve), electric</td>
<td>0.4</td>
<td>440,000</td>
<td></td>
</tr>
<tr>
<td>Toyota RAV4 EV</td>
<td>electric</td>
<td></td>
<td>0.4</td>
<td>800,000 [5] Inc. tax, vat</td>
</tr>
</tbody>
</table>

* Toyota Prius + added Battery kit (8)

Benefit analysis

The PHEV benefit analysis is a simple comparison of cost-of-ownership over the vehicle lifetime. The cost of ownership for some car types is shown in Fig.1. The comparison includes the retail cost of the vehicle and the cost of its annual energy (fuel and electricity) consumption, but does not account for possible differences in maintenance costs (for a more thorough analysis of total PHEV lifecycle costs). Figure 1 presents economic comparison for the near-term scenario, in the calculations of annual petroleum and electricity consumption, all vehicles are assumed to travel 36,950 km per year. The HEV achieves a lower cost-of-ownership than the CV after approximately five years. However, the PHEVs achieve a lower cost-of-ownership also after five years.

Fig. 1 Cost of ownership

HEVs achieve high fuel economy, but they are still designed only for petroleum fuels and do not enable fuel substitution/flexibility. PHEVs, however, are true fuel-flexible vehicles that can run on petroleum or electrical energy. BEVs do not require any petroleum, but are constrained by battery technologies resulting in limited driving ranges, significant battery costs and lengthy recharging times. PHEVs have a smaller battery which mitigates the battery cost and recharging time while the onboard petroleum fuel tank provides a driving range equivalent to conventional and hybrid vehicles. This combination of attributes is building a strong demand for PHEVs, as evidenced by the recently launched Plug-In Partners [7] and other reviews [8, 9].

Conclusion

This paper has presented a comparison of the costs (vehicle purchase costs and energy costs) and benefits (reduced petroleum consumption) of PHEVs relative to HEVs and CVs. Based on the study results, it was found that there is a very broad spectrum of HEV-PHEV designs with greatly varying costs and benefits. Furthermore, the PHEV cost-benefit equation is quite sensitive to a range of factors. In particular, battery costs, fuel costs, vehicle performance, and driving habits have a strong influence on the relative value of PHEVs. Given the large variability and uncertainty in these factors, it is difficult to predict the future potential for PHEVs to penetrate the market and reduce fleet petroleum consumption. However, the potential for PHEVs to reduce per-vehicle petroleum consumption is clearly very high. Without knowing the future costs of petroleum, it is impossible to determine the exact future economics of PHEVs. However, according to the findings, justification of the PHEV capital cost premium on the basis of reduced lifetime energy costs alone seems very challenging. Other incentives and business models may be required to create an attractive value proposition for PHEV motorists. However, the large petroleum reduction potential of PHEVs offers significant national benefits and provides strong justification for governmental support to accelerate the deployment of the PHEV technology. Finally, PHEVs are very marketable in that they combine the beneficial attributes of HEVs and battery electric vehicles (BEVs) while mitigating their disadvantages.

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