Energy Policy 37 (2009) 1095–1103

Contents lists available at ScienceDirect

Energy Policy

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

Beyond batteries: An examination of the benefits and barriers to plug-in hybrid electric vehicles (PHEVs) and a vehicle-to-grid (V2G) transition

Benjamin K. Sovacool [a,*], Richard F. Hirsh [b]

[a] Energy Governance Program, Centre on Asia and Globalisation, Lee Kuan Yew School of Public Policy, National University of Singapore, Singapore
[b] History and Science & Technology Studies, Virginia Polytechnic Institute and State University, Blacksburg, USA

ARTICLE INFO

Article history:
Received 14 July 2008
Accepted 14 October 2008
Available online 30 December 2008

Keywords:
Plug-in hybrid electric vehicle
Vehicle-to-grid
Transportation policy

ABSTRACT

This paper explores both the promise and the possible pitfalls of the plug-in hybrid electric vehicles (PHEV) and vehicle-to-grid (V2G) concept, focusing first on its definition and then on its technical state-of-the-art. More originally, the paper assesses significant, though often overlooked, social barriers to the wider use of PHEVs (a likely precursor to V2G) and implementation of a V2G transition. The article disputes the idea that the only important barriers facing the greater use of PHEVs and V2G systems are technical. Instead, it provides a broader assessment situating such "technical" barriers alongside more subtle impediments relating to social and cultural values, business practices, and political interests. The history of other energy transitions, and more specifically the history of renewable energy technologies, implies that these "socio-technical" obstacles may be just as important to any V2G transition—and perhaps even more difficult to overcome. Analogously, the article illuminates the policy implications of such barriers, emphasizing what policymakers need to achieve a transition to a V2G and PHEV world.

1. Introduction

The vehicle-to-grid (V2G) concept links two critically important technological systems–the electric power system and the petroleum-based transportation system–in ways that may address significant problems in both. By drawing on and supplying power to the power grid, electric vehicles could displace the use of petroleum and mitigate pollution and security issues related to oil extraction, importation, and combustion. It could also improve the economics and technical performance of the electric utility industry and generate revenue to owners of plug-in hybrid electric vehicles (PHEVs). Of course, a host of technical and social impediments exists that forestalls the immediate realization of these potential benefits.

In this paper, we explore both the promise and the possible pitfalls of a transition to PHEVs and the V2G concept, focusing first on its definition and then on its technical state-of-the-art. More originally, we assess significant, though often overlooked, socio-technical barriers to the implementation of a V2G transition, concentrating primarily on the first link of that transition: PHEVs. The term "socio-technical" encompasses not just technological and engineering obstacles, but also cultural, social, political, and economic impediments.

This article acknowledges that many important barriers facing a transition to a V2G system are technical, but it emphasizes that several remain social as well. It provides a broad assessment situating such "technical" barriers alongside more subtle impediments relating to customer behavior in light of economic uncertainties, cultural and social values, business practices, and resistance to infrastructural changes. The history of other energy transitions implies that these "socio-technical" obstacles may be just as important to any V2G transition—and, perhaps because they are often harder to identify, more difficult to overcome.

Because no commercially viable PHEVs currently exist on the market, our assessment has the benefit of informing policymakers *before* they commit to a predetermined technological pathway (Letendre et al., 2006). Given that energy technologies such as refineries and power stations require extremely large capital expenditures, the infrastructure built today will remain in operation for 30–40 years. By identifying a range of barriers to PHEVs and an eventual V2G transition now, we can help inform policymakers early in the process and perhaps avoid spending huge amounts of money on a promising technological pathway that fails to deliver results.

2. Conceptualizing V2G and PHEVs and the technical challenges ahead

Most modern automobiles employ internal combustion (IC) engines, which start quickly and provide power as soon as drivers

* Corresponding author.
E-mail addresses: bsovacool@nus.edu.sg (B.K. Sovacool), richard@vt.edu (R.F. Hirsh).

0301-4215/$ - see front matter
doi:10.1016/j.enpol.2008.10.005

need it. But they operate inefficiently and waste energy when idling (Sanna, 2005). By contrast, hybrid electric vehicles (HEV), which have seen commercial success as the Toyota Prius, Honda Insight, the Honda Civic Hybrid, and others, add a battery and electric motor to a car that uses an IC engine. By marrying advanced power electronics and computer controls with conventional and electric drive trains, HEVs operate more efficiently than those that run on IC engines alone and reduce emissions. They lessen fuel usage because they employ the electric motor frequently (especially in slow traffic), because they shut down the IC engine when the vehicle has stopped for a predetermined amount of time, and because they recapture otherwise discarded kinetic energy during braking (Denholm and Short, 2006; Romm and Frank, 2006). (Table 1).

A "plug-in" or "pluggable" hybrid (PHEV) uses HEV technology, but it features a larger battery and a plug-in charger. Most PHEV prototypes contain a battery capable of powering the vehicle between 20 and 60 miles (about 30–100 km) on electricity alone (Denholm and Short, 2006). In 2008, General Motors (2008), for example, began advertising the Chevrolet Volt, an all-electric vehicle that can operate up to 40 miles on household current without recharging. The company targets 2010 as the novel car's launch date.

Finally, an automobile capable of "vehicle-to-grid" (V2G) interaction, sometimes referred to as "mobile energy" or "smart charging," mates an automobile with the existing electric utility system (Williams and Kurani, 2006, 2007). Vehicles must possess three elements to operate in V2G configuration: a power connection to the electricity grid, a control and/or communication device that allows the grid operators access to the battery, and precision metering on board the vehicle to track energy flows (Tomic and Kempton, 2007). This intelligent, two-way communication between the electricity grid and the vehicle enables utilities to manage electricity resources better, and it empowers vehicle owners to earn money by selling power back to the grid.

PHEVs and V2G systems are thus intimately interconnected. PHEVs have the opportunity to become not only vehicles, but mobile, self-contained resources that can manage power flow and displace the need for electric utility infrastructure (McNamara, 2008). V2G vehicles can reduce the lifetime cost of PHEVs, thereby making them more attractive, and if V2G increases the market share of PHEVs, the benefits of PHEV use increase. In this context, the benefits and barriers facing PHEVs remain interconnected with those facing V2G, which explains our discussion of both of them. Since average vehicles in the United States travel on the road only 4–5% of the day, and at least 90% of personal vehicles sit unused (in parking lots or garages) even during peak traffic hours (Tomic and Kempton, 2007), the size of a possible PHEV V2G resource can be quite large: placing just a 15 kW battery in each of the existing 191 million automobiles in the United States would create 2865 GW of equivalent electricity capacity if all the vehicles supplied power simultaneously to the grid—an unlikely occurrence (Kempton, 2005). (This amount is more than twice than the total nameplate capacity of all American electric generators in 2006).

Table 1
Conventional and unconventional vehicle classifications.

Vehicle type	Engine	Advantages
Conventional	Internal combustion engine	Rapid starting, relatively quick acceleration and power
Hybrid electric vehicle (HEV)	Internal combustion engine with separate electric motor	Regenerative braking and fuel savings
Plug-in hybrid electric vehicle (PHEV)	Larger electric motor and battery with smaller internal combustion engine	Can recharge at night to capture HEV benefits plus an all-electric range varying from 20 to 60 miles (about 30 to 100 km)
Vehicle-to-grid (V2G) PHEV	Larger electric motor and battery with smaller or eventually no internal combustion engine	Captures PHEV benefits and can send power back to the grid

The federal government has begun supporting research on the PHEV and V2G concept partly because these potential benefits can accrue to a society more dependent on electricity than on petroleum. At the US Department of Energy (DOE) and US Department of Transportation (DOT), promotion of research, sometimes known as "R&D pathways," has focused on improving the range, refueling capability, and cost of V2G PHEVs (Romm, 2007). Based on a consensus of technical experts, the pathways have deliberately concentrated on mostly technical and economic issues, which have been seen as the primary impediments to the widespread use of PHEVs. Researchers at the utility-sponsored Electric Power Research Institute (EPRI) have argued, for example, that "there are no major automaker initiatives to develop and introduce PHEVs, presumably because of battery technology readiness and vehicle cost concerns" (Duvall, 2002). Experts convened at DOE conferences have identified a broad range of barriers facing V2G systems, but have also stated that "cost is the primary impediment to producing PHEVs" (Wellinghoff and Kempton, 2007). Reiterating this commonly held view, President George W. Bush, in his 2007 State of the Union Address, commented on the economic and technical impediments of PHEVs and urged engineers "to press on with battery research for plug-in and hybrid vehicles" (Bush, 2007). Finally, the US Department of Energy's Energy Efficiency and Renewable Energy Program (2007) managers have succinctly emphasized the point, by noting that "cost is the primary impediment and battery technology is a potential show stopper for production."

This understandable logic leads R&D managers (in government and in corporations) to pursue research activities in materials and processing, power electronics, low-cost and lightweight materials, and grid interaction. They have laid out an extensive R&D program aimed at improving batteries' conductivity and mechanical strength. Batteries, notes an EPRI report, remain the "chief concern" of current research (Sanna, 2005). Indeed, we certainly agree that the technical and economic barriers facing PHEVs and V2G technologies remain important. However, as we will see after exploring the benefits of a V2G transition, such barriers are not the only significant ones.

3. The potential benefits of a V2G transition to the petroleum-based transportation system

The V2G concept excites advocates because it offers mutual benefits to the transportation and the electric power systems. It could assist the former by reducing petroleum use, strengthening the economy, enhancing national security, reducing strain on petroleum infrastructure, and improving the natural environment. It could help the latter by providing a new demand for electricity, ideally during the parts of the day when demand remains low. Moreover, it could add capacity to the electric grid during peak times without the need for the utility industry to build new power plants.

Focusing on the transportation sector, the US DOT (2003) estimates that about 60% of vehicles travel fewer than 30 miles (about 50 km) per day. A PHEV with a battery capable of a 30-mile range could, therefore, eliminate petroleum use for these short trips and cut overall liquid fuel use by as much as this amount (Romm and Frank, 2006). The numbers quickly add up: a transition to a V2G strategy has the potential to displace