

PLUG-IN ELECTRIC HYBRID VEHICLES AND THE POWER GRID: IS YOUR UTILITY PREPARED FOR THE CHANGES AHEAD?

By Tom Hulsebosch, Fred Pammer, and John Hightower

The market for plug-in hybrid electric vehicles (PHEVs)—vehicles that can get up to 150 miles per gallon—is poised for significant growth over the next several years, and not just because of their potential impact on the environment. The incoming administration has stated that its goal is to put one million PHEVs on the road by 2015.

Increasingly, PHEVs will have a major impact on the electric power grid. West Monroe Partners' analysis of one Midwestern utility shows that every 10-percent increase in the number of customers with PHEVs will raise total energy consumption by two percent. This is both an opportunity and a concern for electric utilities, which must manage peaks in demand proactively in order to control electricity costs. If this extra demand can be predictably moved to a non-peak time, when low-cost base load generation is available, the incremental cost of the electricity to charge a PHEV can be relatively low.

Analyses show that charging a PHEV battery will create between one and four kilowatt hours of demand. If thousands of PHEV owners plug in their vehicles at the same time, such as when the typical workday ends, this can create a dramatic increase in the instantaneous energy demand on the utility's generation facilities, along the distribution feeder, and at the substation.

Plug-in hybrids have a significant impact on emissions and the environment. West Monroe Partners' analysis found that consumers who use PHEVs rather than conventional automobiles for shorter trips can expect to produce substantially less carbon dioxide (CO₂) emissions. Yet, there are some concerns about increased emissions due to the generation of the electricity to

charge the car in locations that have many fossil fuel power plants.

Most industry observers believe that PHEV adoption is inevitable, and that it will have a significant impact on how utilities operate, deliver, and price electricity. These vehicles will lead to an increase in Time of Use (TOU) electric rates—rate plans under which consumers pay differing rates depending on the time of day, with higher rates during hours of peak demand and lower rates during off-peak hours.

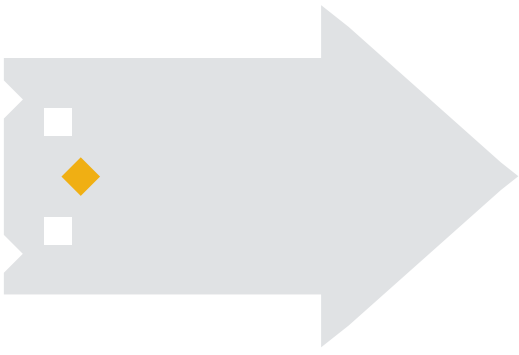
Utilities should be preparing today for the integration of PHEVs and the power grid. Is your utility prepared for the changes ahead?

PLUG-IN HYBRID ELECTRIC VEHICLES: THE CURRENT STATE

Plug-in hybrid electric vehicles are dual-mode hybrids that include both a hybrid electric/gasoline mode and a fully electric mode of operation that utilizes an auxiliary battery. A PHEV owner can drive around town in all-electric (or "zero") mode and then switch to hybrid mode for longer distances for which the auxiliary battery is insufficient. Because most trips are short, a driver can operate most of the time without burning gasoline—using cleaner electric energy for a fraction of the cost per mile compared to operation in the gasoline mode.

Plug-in hybrid electric vehicles are still in the early stages of development and require advanced technologies to manage the battery charging/discharging cycles. Unlike the hybrids produced today by Toyota, Ford, Honda, General Motors, and others, PHEVs are not currently commercially manufactured.

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THE IMPORTANCE OF INTEGRATING PHEVS WITH THE POWER GRID

With sufficient penetration of PHEVs, electric utilities can expect to see significant energy and demand increases when large numbers of users plug in and charge their vehicles. If most owners plug their vehicles into the grid at the same time, it could produce costly consequences for utilities because it would require them to purchase additional capacity to meet peak demands. Utilities, therefore, must plan proactively for integrating PHEVs with the power grid.

By offering incentive TOU rates that encourage “smart charging,” utilities can shift the PHEV charging load to off peak hours and avoid higher peaks in demand, as demonstrated in the exhibit below. If PHEV demand can be predictably moved to a non-peak time, when low cost base load generation is available, the incremental cost of the electricity to charge a PHEV can be relatively low.

OPPORTUNITIES FOR UTILITIES AND CONSUMERS

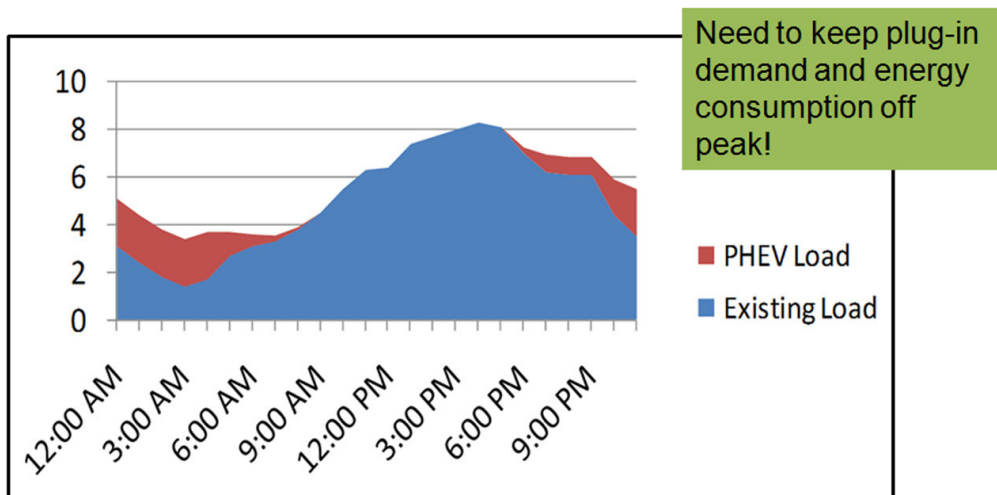
From all sides—consumer, government, utilities, and manufacturers alike—there is great interest in PHEVs and other electric and hybrid gasoline/electric vehicles. Offering an

alternative to gasoline or diesel transportation, these vehicles provide opportunities to reduce oil consumption, reduce emissions from burning fossil fuel, and provide economies for the consumer.

Utility benefits. For the country’s electric utilities, the interest in and potential penetration of all forms of electric vehicles presents both opportunities and challenges. Utilities can increase their revenue by delivering additional off-peak power required to charge these vehicles—but they must be wary of managing the impact on demand peaks. By diverting charging to non-peak periods and potentially using the energy stored in PHEV batteries to shave load, utilities can generate substantial benefits from the integration of PHEVs.

Finally, by playing an “early adopter” role and encouraging PHEV technology, utilities can improve their relationships with regulators and the public. With growing pressure to incorporate “green” incentives in rate decisions, a utility on the leading edge of this movement may be able to establish the ground rules and maximize its benefits.

Consumer benefits. Consumers also can benefit—by reducing energy costs and participating in “green” alternatives to oil. They also can take advantage of other incentives, including



The PHEV and EV create an additional ~15% long term increase in MWh in “Off Peak Time” using AMI, Smart Grid and Special TOU Rate Plan.
(Load is based on 70% penetration of PHEV and EV’s in residential market.)



In addition to reducing dependency on oil, consumers may derive significant benefits by integrating PHEVs with the utility grid. For example, PHEV owners may:

- ◆ Gain fuel efficiency improvements over gasoline engines; by using smart charging, consumers could save as much as \$1,000 per year. Studies have predicted average fuel savings of \$1,032 per year. When combined with estimated “smart charging” savings of \$214 per year, a PHEV owner could expect to save \$1,247 per year.
- ◆ Reduce CO2 emissions by 1.5 tons per year compared to driving a fuel-efficient gasoline automobile. Assuming 95 percent of the miles that a PHEV owner drives are short trips (35 miles or less), drivers can expect to reduce total carbon dioxide (CO2) emissions by 69 percent by choosing a PHEV over a conventional vehicle. If consumers choose a PHEV over a standard hybrid, they can expect to reduce CO2 emissions by 53 percent.
- ◆ Connect bi-directionally to the grid and use the plug-in battery as a back-up electricity source for the home during an outage.
- ◆ Sell power back to the grid (possibly a reality in the near future), ultimately providing consumers with the choice to buy electricity at low rates and sell at high rates.

TRENDS AFFECTING PHEV ADOPTION

Battery technology. For all electric vehicles, the battery is critical to success and customer satisfaction. In fact, battery technology is one reason that electric vehicles have not penetrated the market further. Most of the hybrid and electric vehicles developed to date use nickel metal hydride (NiMH) batteries. Although acceptable for current applications, vehicles scheduled to come on line in the next 10 years require battery technology that produces higher output at a reduced cost and weight.

Battery technology is particularly important for PHEVs. The auxiliary battery provides power without use of the gas engine; therefore, the capacity of this battery and, hence, the available electric mode travel distance will be critical to convincing customers to adopt.

Battery capacity—i.e., the ability to deliver current to the electric

motor in sufficient quantity—is beginning to reach a point that will support consumer requirements and potentially propel PHEVs into the mainstream. Advances in lithium-ion battery technology can support a much higher energy-to-weight ratio, thereby making higher capacity batteries adaptable to an automobile. In fact, development of lithium-ion batteries has progressed to such an extent that they are now being given strong consideration as a replacement for NiMH batteries.

A study by the University of California Davis¹ analyzes battery development in detail, including the wide variety of possible materials that is allowing battery manufacturers to pursue several different development paths. Several alternative chemistries are being tested for PHEVs, including:

- ◆ Cobalt and aluminum (NCA)
- ◆ Cobalt and manganese (NCM)
- ◆ Lithium iron phosphate (LFP)
- ◆ Lithium manganese spinel (LMS)
- ◆ Lithium nickel Lithium titanium (LTO)
- ◆ Manganese titanium (MNS and MS)

The table¹ on the following page describes several of the key battery technologies and their development status. In addition, it illustrates the many inherent tradeoffs in battery development, including power, energy, life, safety, and cost goals.

Battery development, however, remains a work in progress. The UC Davis study found that no one battery type has met all of the goals for long-term sustainability of the PHEV platform. In addition, there are safety concerns about using these types of batteries for automotive applications.

Common standards. One of the keys to penetration of PHEVs will be a common approach across utilities for integrating PHEVs with the power grid.

In March of 2008, the Electric Power Research Institute (EPRI) and Ford Motor Company announced a three-year agreement to develop and evaluate technical approaches for integrating PHEVs into the nation’s electric grid system. The institute initially will work with a consortium of utilities in the New York-New Jersey area to

1. Axsen, J., Burke, A, and Kurani, K, (2008) Batteries for Plug-In Hybrid Electric Vehicles (PHEVs) Goals and the state of the Technology Circa 2008 USD-ITS-RR-08- Institute of Transportation Studies, University of California Davis, CA.



ILLUSTRATIVE “SNAPSHOT” OF LI-ION PHEV BATTERY CHEMISTRIES¹

Name	Description	Electrodes: Positive (Negative)	Companies	Automotive Status	Power	Energy	Safety	Life	Cost
LCO	Lithium Cobalt Oxide	LiCoO ₂ (Graphite)	Various consumer applications (not automotive)	Limited auto applications (due to safety)	Good	Good	Low Mod.	Low	Poor
NCA	Lithium Nickel, Cobalt, and Aluminum	Li(Ni _{0.85} Co _{0.1} Al _{0.05})O ₂ (Graphite)	JCI-Saft GAIA Matsuhita Toyota	Pilot	Good	Good	Mod.	Good	Mod.
LFP	Lithium iron phosphate	LiFePO ₄ (Graphite)	A123 Valence GAIA	Pilot	Good	Mod.	Mod.	Good	Mod. Good
NCM	Lithium Nickel, Cobalt, and Manganese	Li(Ni _{1/3} Co _{1/3} Mn _{1/3})O ₂ (Graphite)	Litcel (Mitsubishi) Kokam NEC Lamillion	Pilot	Mod.	Mod. Good	Mod.	Poor	Mod.
LMS	Lithium Manganese Spinel	LiMnO ₂ or LiMn ₂ O ₄ (Li ₄ Ti ₅ O ₁₂)	GS Yuasa Litcel (Mitsubishi) NEC Lamillion EnerDel	Devel.	Mod.	Poor	Excel. Good	Excel. Mod.	Mod.
LTO	Lithium Titanium	LiMnO ₂ (LiTiO ₂)	Altaimano Enerdel	Devel.	Poor Mod.	Poor	Good	Good	Poor
MNS	Manganese titanium	LiMn _{1.5} Ni _{0.5} O ₄ (Li ₄ Ti ₅ O ₁₂)		Research	Good	Mod.	Excel.	Unkwn.	Mod.
MN	Manganese titanium	Li _{1.2} Mn _{0.6} Ni _{0.2} O ₂ (Graphite)		Research	Excel.	Excel.	Excel.	Unkwn.	Mod.

This partnership’s evaluation and demonstration trials are designed to provide technical information about PHEVs that will enable the development of common standards for accommodating these vehicles.

Impact on carbon emissions. Government, utility, and educational institutions have conducted a number of studies of PHEVs and their effect on the power grid. Some of these studies have questioned the overall impact to the environment when taking into account the total system.

In May 2007, Xcel Energy² completed a study that used simulation to quantify the effect of PHEV-charging techniques on utility system operations within the utility’s Colorado service area. The National Renewable Energy Laboratory also participated in the study. The study evaluated the results of using four different

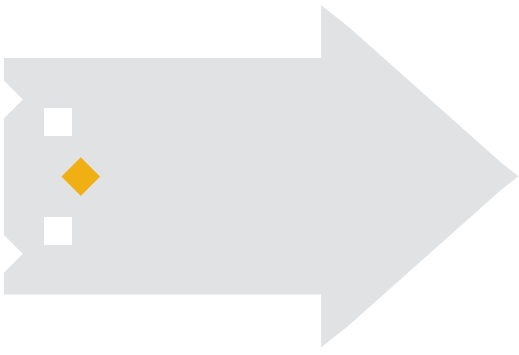
charging algorithms to examine reduced dependence on gasoline, impact on energy production costs, and reduction of utility and vehicle emission footprints.

By implementing a “smart charging” program that optimized charging patterns during lowest load hours, Xcel showed that generation costs could be reduced by \$53 per car annually. Or, by simply delaying vehicle charging until 10 p.m., the savings could be \$41 per car annually. Charging “continuously”—that is, having the ability to charge wherever the vehicle is parked—reduces the use of gasoline even further.

The study did raise a concern that using the “optimized” charging pattern could produce higher levels of total greenhouse gas emissions, even compared to a “do nothing” charging strategy, in cases where the utility has a high percentage of fossil fuel plants—as Xcel Energy does.

1. Axsen, J., Burke, A, and Kurani, K, (2008) Batteries for Plug-In Hybrid Electric Vehicles (PHEVs) Goals and the state of the Technology Circa 2008 USD-ITS-RR-08- Institute of Transportation Studies, University of California Davis, CA.

2. Parks, K., Denholm, P., Markel, T., Costs and Emissions Associated with Plug-In Hybrid Electric Vehicle Charging in the Xcel Energy Colorado Service Territory, NREL/PO-64-40694 National Renewable Energy Laboratory, Golden, CO.



Future studies must seek to understand the optimal generation mix before making assumptions about emission reductions. For example, the Colorado service area is heavily dependent on coal and gas fired power plants. Other U.S. service areas may not be as dependent and as such, PHEV charging may not have the same effect on greenhouse gas emissions.

Oak Ridge National Laboratory³ conducted a study, presented in August 2007, that used the Oak Ridge Competitive Electricity Dispatch model to evaluate the impact of PHEVs on the Virginia-Carolinas electric grid in 2018. The results show that changing the charging times can have a distinct impact on fuels and generating technologies. At low specific power and late in the evening, coal was the major fuel used, while charging more heavily during peak times led to more use of combustion turbines and combined cycle plants.

Depending on the power level, timing, and duration of the PHEV connection to the grid, there could be a wide variety of effects on grid constraints, capacity needs, fuel types used, and emissions generated.

THE TIME TO ACT IS NOW.

Through the investments utilities are making today in Smart Grid technology, they can facilitate the integration of tomorrow's PHEVs with their power grids. Specifically, utilities can further their efforts by considering technology that:

- ◆ Gathers energy usage data for and tracks load impacts and energy consumption of PHEVs
- ◆ Monitors and controls individual PHEV charging circuits at homes, allowing for precise demand response solutions

Penetration of PHEVs is inevitable, and their impact on the utility grid must be managed or the impacts could become significant. Utilities have an opportunity to plan proactively today to ensure they are prepared to integrate PHEVs into their power grid. The need to do so will be here before we know it.

WEST MONROE PARTNERS

West Monroe Partners' Energy & Utilities team has deep knowledge of the issues and trends affecting the industry—experience gained through years of working with respected industry leaders to improve operations and address their evolving business environment.

3. Hadley, S., *Evaluating the Impact of Plug-in Hybrid Electric Vehicles on Regional Electricity Supplies* IEEE 1-4244-1519-5/07/Oak Ridge National Laboratory, Golden, CO.

- West Monroe Partners is an international, full-service business and technology consulting firm focused on guiding organizations through projects that fundamentally transform their business. With the experience to create the most ambitious visions as well as the skills to implement the smallest details
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