

The prospect of millions of vehicles plugging into the nation's electric grid in the coming decades never has been better. In 2005, hybrid electric vehicles (HEV) reached 1.2 percent of new cars sold in the United States, more than doubling the number sold in the prior year. Vehicle manufacturers, betting on this trend accelerating in the coming years, are rushing to bring HEVs to their dealers' showrooms.

The evolution of HEVs to allow charging from the electric grid—so called plug-in hybrids (PHEV)—is assumed by many to be desirable, even inevitable. Indeed, a growing movement to bring PHEVs to market has emerged, bolstered by the undeniable economic and national-security benefits that result from displacing gasoline with electricity.

One highly visible grassroots campaign called Plug-In Partners seeks to demonstrate to the major automobile manufacturers that a national market exists for flexible-fuel PHEVs; dozens of businesses, utilities, municipal governments, and environmental groups have joined the Plug-In Partners campaign.

While there are no commercially available PHEVs on the market, a number of prototypes have been built and tested. The most established PHEV program is housed at the University of California Davis, where Professor Andrew Frank works with students designing and building prototype PHEVs. A second development project involves collaboration between the Electric Power Research Institute (EPRI) and DaimlerChrysler. They produced, and are in the process of testing, several prototype plug-in hybrid vans using the Sprinter platform. (*Editor's Note: Tesla Motors recently introduced an all-electric vehicle. See sidebar, p. 34.*)

Two startup firms plan to offer conversion kits for current generation hybrid electric vehicles to allow grid charging of the on-board battery pack. These conversions kits offer the potential to almost double an HEV's fuel efficiency rating to 100+ miles per gallon by increasing the size of the battery storage system and installing the hardware and controls to allow charging from the electric grid.

There is some indication that at least one major auto manufacturer is developing next generation PHEV technology. This summer, Jim Press, president of Toyota's North American subsidiary, announced that the company was looking at developing a plug-in hybrid that travels greater distance without gasoline than their current hybrid models. Toyota is the leading manufacturer of HEVs, selling over 50 percent of all hybrids purchased in the US in 2005.

The authors believe that the commercial success of PHEVs

► The all-electric Tesla Roadster can go from 0 to 60 in about 4 seconds (see p. 34).

ELECTRIC & HYBRID CARS

NEW LOAD,

The industry must join a growing chorus in calling for new technology.



BY STEVEN LETENDRE, PH.D., PAUL DENHOLM, PH



Photos courtesy of Tesla Motors



will hinge on an aggressive development and marketing effort by a major auto maker. Support from the electric-power industry could provide further impetus for a major automobile manufacturer, such as Toyota, to pursue PHEV technology.

The potential that PHEVs offer to lower fuel costs, reduce petroleum consumption, and decrease harmful emissions is described elsewhere.¹ The likely impact on the electric grid from an increasing number of vehicles plugging in is not yet fully understood. This is due in part to key variables that are difficult to predict, such as likely PHEV design characteristics (e.g., battery size and efficiency) and market penetration rates.

OR NEW RESOURCE?



H.D., AND PETER LILIENTHAL, PH.D.



This article sheds light on these important issues using reasonable assumptions for each of these key variables.

We begin with an assessment of the increased load that PHEVs would represent under a range of assumptions. Next, we evaluate PHEVs serving as distributed-power resources, targeting high-value markets for fast response, short duration grid-support services; this concept has become known as vehicle to grid.² Finally, we summarize the opportunity and challenge that PHEVs represent to the electric power industry.

We believe the system-wide impacts of an emerging fleet of PHEVs are fully understood only when these vehicles are

considered as both new load and new, distributed resources.

Electrons for Gasoline

Ultimately, the economics of displacing gasoline with electricity should drive consumer demand for PHEVs. The cost of electricity to drive a vehicle the same distance as one gallon of gasoline is equal to approximately \$1—or even less if off-peak electricity prices are assumed.³ Furthermore, as discussed later in this article, PHEVs potentially could generate revenue for the vehicle owner by providing grid-support services. Combined, these value propositions could serve to usher in an era

of advanced vehicles with dramatic reductions in gasoline use and tailpipe emissions.

Can the current and planned electric-power infrastructure meet the increased demand from PHEVs?

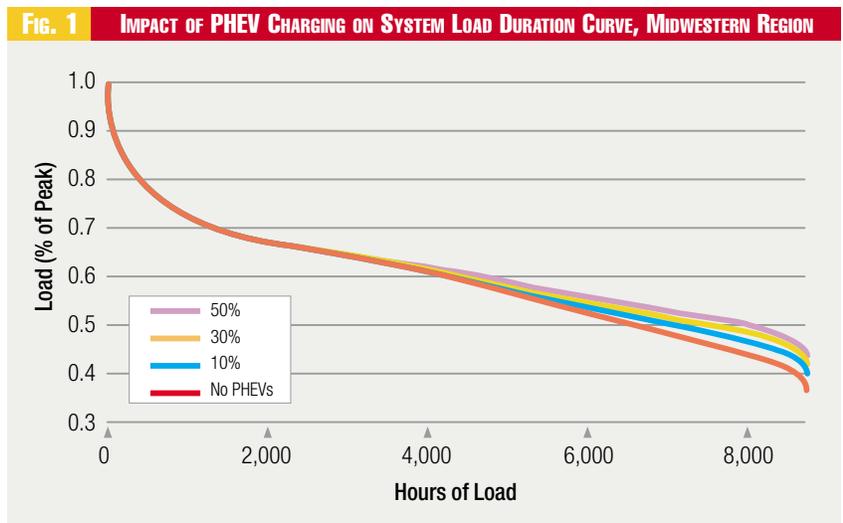
Fig. 1 presents load-duration curves under a range of assumption about PHEVs, from a base case with no PHEVs to an aggressive case assuming 50 percent penetration. The graph illustrates that PHEV charging does not necessarily contribute to the system peak, provided an optimized PHEV charging regime is adopted. The graph was generated using a PHEV-load tool, which simulates PHEV charging on an optimized 24-hour cycle for a utility control area in the Midwest. This simulation was performed for six different regions for which hourly electric load data was available. The results presented in Fig. 1 were consistent across the six regions.

The NREL study assumed that 40 percent of the PHEV daily miles traveled were obtained using electricity. This is equivalent to a PHEV with an all-electric range of between 20 to 40 miles—so called PHEV20 and PHEV40 respectively. While uncertainty exists about the PHEV architecture that is most marketable, the National Economic Council's Advanced Energy Initiative established PHEV40 as its goal.⁵ Depending on the average vehicle miles traveled in each region, between 4 kWh and 6 kWh on average per day are needed to meet 40 percent of drive miles with electricity. Fig. 2 presents estimates of the increased energy consumption for each region by PHEV penetration rate. This type of new load represents an opportunity for the electric utility industry to expand sales without contributing to system peak.

Further benefit to the electric-power sector from the introduction of PHEVs include increased load factor, for both generation and transmission facilities, and reduced cycling of generation facilities. The economic value of these benefits, which are a function of the cost structure for each individual utility operating within a particular geographic location, was not calculated.

What's the Real Potential For PHEVs?

Conventional thinking suggests that PHEVs would plug in at night and recharge during the late evening and early morning hours—end of story. This perspective is limited, and misses a



significant value proposition that is made possible by the fact that vehicles are parked over 90 percent of the time. These idle resources, if connected to the grid when parked, could be tapped to provide any number of grid services.

It should be noted here that we consider only the stored energy in the onboard battery pack of a PHEV as available for vehicle-to-grid (V2G) power, unlike earlier studies of PHEVs providing V2G power.⁶ We do not consider remote starting of vehicles to access the liquid fuel onboard as reserve energy for V2G power. While this is technically feasible, the control and safety issues associated with starting engines remotely are a cause for concern and thus we do not consider this as a near-term option. PHEVs have larger battery packs than HEVs, and unlike a pure battery-only electric vehicle, the entire available energy in a PHEV can be used for V2G services given that when the owner begins the next trip the vehicle can use the liquid fuel to drive the vehicle.

While the authors know of just one demonstration project,⁷ V2G has been analyzed primarily from a theoretical perspective.⁸ While no major technical barriers to V2G emerged from the demonstration project or the research, several issues bearing on the economic potential of cars providing grid support services were identified.

While V2G-capable cars could provide peak power or serve as a demand-response resource, their economic values do not generally justify the expense.⁹ These services are needed for just a few hours each year, and thus the potential revenue from providing these services is limited. Research on the subject found that the most promising markets for V2G power are for those services that the electric industry refers to as ancillary services. These are services that grid operators must obtain 24 hours per day 7 days per week, and thus take advantage of the extended availability of the vehicle fleet to provide these services.

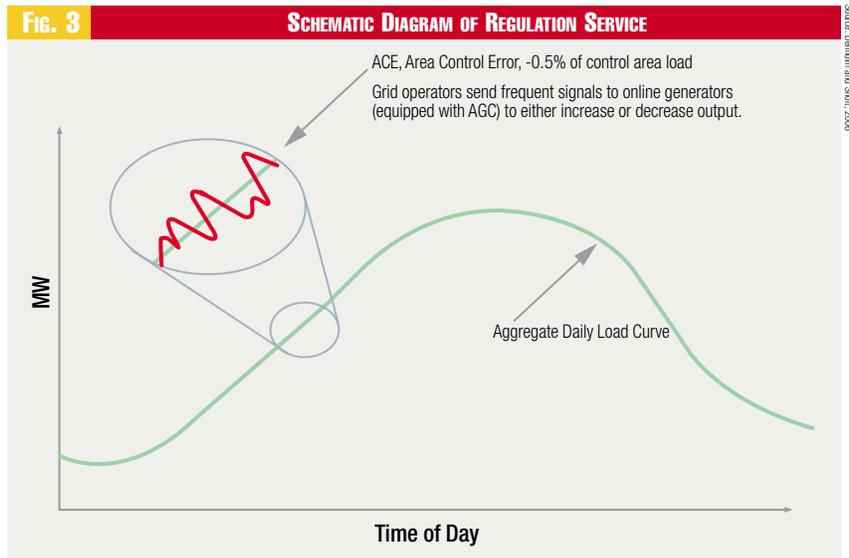
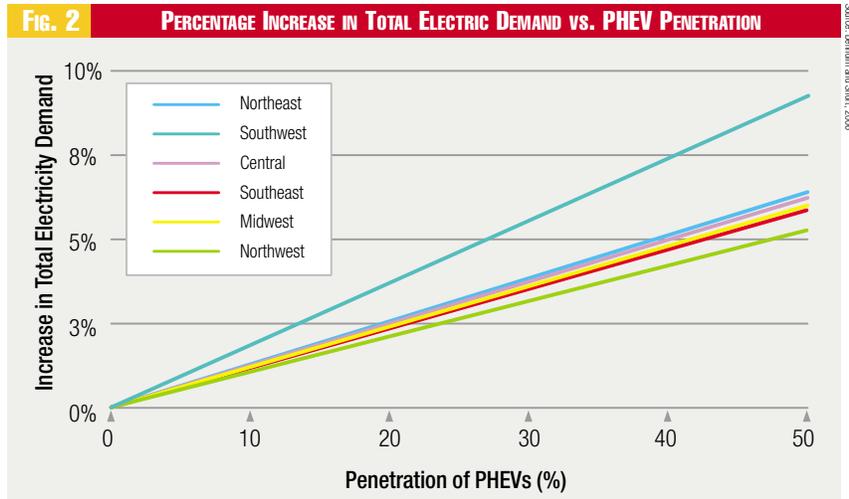
Earlier studies identified two specific ancillary services, for which hourly wholesale markets exist, as particularly promising for V2G power—regulation and spinning reserves. Vehicles with an electric-drive system and battery storage, like those found in PHEVs, particularly are well suited to provide these services, which fall under the general category of operating reserves. These services require fast and accurate responses to electric-grid operator signals, and typically are used for short durations. Grid operators across the country require each of these services for every one of the 8,760 operating hours in a year, and they represent a multi-billion-dollar combined market.

Regulation (frequency response) services today are supplied by generators on automatic generation control (AGC), which are deployed based on a measurement called area control error (ACE)—a measure that characterizes the instantaneous mismatch between supply and demand. Control area operators are required by the national and regional reliability organizations to carry sufficient regulation reserves equal to approximately 1.5 percent of the control area's peak demand for power in a given day. These reserves must provide both regulation up and regulation down, depending on the ACE, in response to a signal sent by the control area's energy management system, which go out literally every two to six seconds. If demand is greater than supply at any given moment, then regulation up is required, and a signal would go out requiring generators to increase the power delivered to the grid. In contrast, in a situation when demand is less than supply, the AGC signal would call upon the regulation reserves to reduce the power delivered to the grid. In the case of a distributed storage system like a PHEV, regulation up entails discharging of the battery and regulation down entails charging of the battery pack.

The second most valuable category of fast-response, short-duration ancillary services is referred to as spinning reserves. These typically are provided by generators that are spinning

and ready to deliver power to the grid in a matter of minutes when called upon in the case of a contingency. These reserves are used only when a scheduled generator trips offline or a transmission or distribution facility fails, and must be up to full power within 10 minutes. Experience shows that spinning reserves rarely are called upon and when they are called, are required for only a short amount of time. In fact, the PJM Interconnect, the regional transmission organization (RTO) serving the Atlantic coastal states and much of the Midwest, experienced 105 events that required deployment of spinning reserves in 2005 with an average duration of 12 minutes.

The central issue dictating the potential V2G revenue from providing these ancillary services is the quantity of power in kilowatts (or capacity credit) per vehicle or fleet. Ultimately, the regulatory authority responsible for qualifying resources to participate in ancillary services markets, like an independ-



ent system operator (ISO), RTO, or regional reliability councils, establish methods to determine the amount of power a resource is able to sell in a given market.

Although emerging competitive markets for grid services purport to be technology neutral, the rules are written to accommodate the incumbent technologies and are not necessarily appropriate for new technologies such as a fleet of V2G capable vehicles. For example, the Northeast Power Coordinating Council, the reliability council covering the Northeastern section of North America, requires minimum run times of one hour for resources providing 10-minute spinning reserves. In practice, however, spinning reserves rarely are called, and when they are, the typical dispatch duration is much less than one hour. Thus, as discussed below, a one-hour dispatch requirement severely would limit the per-vehicle power a PHEV would be able to sell in a market for spinning reserves, and fails to appreciate the value of a rapid and accurate response that a V2G system is capable of.

The key parameter for resources providing regulation reserves is the generating unit's ramp rate.¹⁰ Most regions specify regulation as a five-minute service. Thus, a generator with a ramp rate of 3 MW/minute in a region that defines regulation as a five-minute service, would be approved to provide 15 MW of regulation. The rules do not specify the power output duration that a resource must maintain, and for which it was approved. PHEVs providing regulation would have ramp rates far superior than the incumbent technologies. Industry experts indicated that inaccurate response to AGC signals requires grid managers to carry greater amounts of regulation reserves than would be necessary if resources were responding precisely to an AGC signal. Again, PHEVs with a communication and control infrastructure would be capable of very accurate responses to signals received from a central grid operator.

For the moment we set aside the regulatory requirements for resources to qualify as providers of ancillary sources, and look at the infrastructure and vehicle constraints that dictate the reverse power flow potential from PHEVs. Kempton and Tomic (2005)¹¹ identify three key factors that limit the amount of power a grid-connected car can deliver back to the grid. These include the onboard vehicle electronics, capacity of the plug circuit, energy storage capacity, and state of charge when the vehicle is plugged in to provide grid services. The key question is which of these serves as the limiting factor to the reverse power flow potential from a PHEV?

We don't anticipate that a PHEV vehicle's power electronics would create a binding limit on the amount of power that can be exported to the grid. PHEVs require high-power components for acceleration and to optimize vehicle performance. An existing electric drive train developed and manufactured by AC Propulsion provides 80 amps in either direction, allow-

While grid-capable cars could provide peak power...the most promising markets are for ancillary services.

ing 19.2 kW of power output.

Thus, the critical factors dictating the reverse power potential come down to the capacity of the plug circuit and the size and state of charge of the PHEV's battery pack. We assume that PHEVs would plug in to conventional residential and commercial circuits with a 120-V 20-amp service allowing approximately 2 kW of reverse power flow. Most homes and commercial buildings contain higher capacity circuits like 240 V at 50 amps for large appliances like ovens and dryers: These circuits could accommodate about 10 kW of reverse power flow from a vehicle back to the electric grid.

The parameters to evaluate with the most potential for variability that limits the amount of power a PHEV could deliver to the grid are: 1) size of the onboard battery pack; and 2) state of charge when plugged in and ready to provide regulation or spinning reserves. For purposes of demonstration, we assume that the average available energy from a fleet of PHEVs is 10 kWh: This is consistent with the energy storage needs of vehicles designated as PHEV20 (larger, less efficient vehicles) and PHEV40 (smaller, compact cars with higher efficiencies). Table 1 illustrates the available V2G power from a PHEV based on a range of assumptions regarding battery state of charge and the duration of the dispatch. The values in Table 1 are calculated simply by multiplying the available energy by the state of charge and then dividing by the dispatch duration. For simplicity, we do not account for the slight losses associated with the inverter to convert the DC battery power to AC grid power. These results are based on a PHEV with 10 kWh of available energy, and thus would scale down for smaller battery packs and scale up for PHEVs with larger battery storage systems.

The data in Table 1 suggests that, as expected, the power capacity per vehicle is highest with a full battery and shorter dispatch durations. In these cases, the capacity of the plug circuit presents the limiting constraint on available power per

vehicle. In all but two cases presented in Table 1, a conventional wall outlet allowing 2 kW of reverse power flow sets the limit on the power being exported to the grid and thus what a vehicle can sell. A higher power circuit allowing 10 kW of reverse power flow readily is available for most homes, but may need to be installed at a location that would allow grid charging of a parked PHEV. With these higher power circuits, about half of the possible situations presented in Table 1 would be limited by the 10-kW plug circuit limit.

We provide some basic calculations on the potential annual revenue assuming a 2-kW and 10-kW limit on reverse power flow from a parked PHEV. Assuming 50 percent state of charge and that the regulatory authority specifies run times of 30 minutes for spinning reserves and 15 minutes for resources providing regulation services, the PHEV would be allowed to sell 10 kW and 20 kW of power into the market for spinning reserves and regulation respectively. In both cases the limiting factor for reverse power flow is the rating of the plug circuit—2 kW and 10 kW.

Kempton and Tomic (2005)¹² provide detailed equations for calculating revenue and costs for various vehicle configurations. Here, we take average market clearing prices from two control areas—PJM and ERCOT (the Electric Reliability Council of Texas)—to estimate the annual revenue to a PHEV owner from providing regulation and spinning-reserve services. Table 2 provides for the average 2005 market-clearing prices from both regions and both grid services.

Further, we assume that the vehicle is plugged in and ready to provide grid services for 75 percent of the available hours in a given year. We consider only capacity payments, however most rules include compensation to resources for energy delivered. We found that this generally nets out when one considers the energy that must be purchased to charge the vehicle. Fig. 4 presents the annual potential revenue to a vehicle owner assuming 2 kW and 10 kW power availabilities.

The results in Table 3 suggest that PHEVs could generate signifi-

cant revenue to a PHEV owner, from a low of \$184/year to a high of \$3,285/year. Relaxing the run-time requirement for resources providing spinning reserves from 60 minutes to 30 minutes dramatically improves the revenue potential of vehicles providing this service. When regulation resources are used appropriately, as we assume a maximum of 15-minute dispatch duration, as the capacity of the plug circuit always will serve as a binding constraint and thus dictate the potential annual revenue from providing this service. Larger circuits could be installed to address this constraint at a cost.

An issue that is not yet fully understood for storage resources providing regulation relates to the random nature of providing regulation services. As mentioned above, the storage resource would need to release energy on to the grid when a regulation up signal is received and absorb energy (charge) when a regulation down cycle is received. A prolonged period of regulation down, for example, could result in the battery pack becoming fully charged. In this case, the vehicle would be unable to provide regulation down if the need persisted. Related

to this issue is what has been labeled the “dispatch-to-contract” ratio, which indicates on average what portion of the regulation reserves being held by the grid operator actually are deployed.¹³ This has implications for the amount of energy throughput for an energy storage system providing this service.

Fig. 4 presents data from ERCOT comparing the amount of regulation being held in reserve versus what was actually deployed to correct the mismatch between supply and demand on a particular day. The AGC signals are given in 15-minute intervals, whereas in practice these signals are sent every few seconds. We assume that this 15-minute data is the average AGC signal during that interval. We are unaware of ISOs or RTOs that make actual AGC signal datasets available to the public. This data would be valuable to clearly understand AGC signal patterns, and their impact on a storage resource providing this service.

While Table 3 provides only revenue, the key (*Cont. on p. 36*)

SOC	Duration of Dispatch (minutes)			
	15	30	45	60
100%	40	20	13	10
90%	36	18	12	9
80%	32	16	11	8
70%	28	14	9	7
60%	24	12	8	6
50%	20	10	7	6
40%	16	8	5	4
30%	12	6	4	3
20%	8	4	3	2
10%	4	2	1	1

	Spinning Reserves	Regulation
PJM	\$14 / MW-h	\$50 / MWh
ERCOT	\$17 / MW-h	\$38 / MWh

	Spinning Reserves		Regulation	
	2 kW	10 kW	2 kW	10 kW
PJM	\$ 184	\$ 920	\$ 657	\$ 3,285
ERCOT	\$ 223	\$ 1,117	\$ 499	\$ 2,497

TESLA: REDEFINING THE ELECTRIC CAR

By Michael T. Burr



“Golf-cart syndrome” long has afflicted the electric-vehicle market. That is, most electric vehicles offered to date have been underpowered and dorky. Thus, the market for EVs effectively has been limited to a few tree-huggers and utility vehicle users.

A well-funded Silicon Valley startup, however, systematically is obliterating golf-cart syndrome. Tesla Motors Inc. has begun selling the Tesla Roadster, a lithium-ion powered sports car that goes from 0 to 60 mph in about 4 seconds. It cruises extremely efficiently, at the equivalent of 135 mpg, with a 250-mile range. And, as the photos illustrate, it's gorgeous—probably because it was designed by a Lotus engineer.

Goodbye golf cart, hello sweet ride.

Public Utilities Fortnightly recently spoke with Tesla Motors CEO Martin Eberhart to learn how Tesla's future might affect electric utilities, and vice versa.

Fortnightly: What's your long-term business plan for Tesla Motors?

Eberhart: Our long-term goal is to become a major car manufacturer. It's bold and audacious, but that's what we

are trying to do.

Instead of starting at the bottom end, we're starting with a car that people will aspire toward. This will change the way people think about electric cars in a fundamental way, and open the door for a whole line of vehicles.

Our second model, currently code-named White Star, will be a five-seater sedan that will appeal to more people. We want to build a factory for the White Star program somewhere in the United States. We're doing it as fast as we can. We hope to begin production in 2009.

Fortnightly: What's the exit strategy for your investors? IPO, buyout, or something else?

Eberhart: We don't have plans for

either an IPO or buyout. I can't imagine who would buy us out of this market; most car companies are jettisoning assets rather than buying them. But an IPO is on the minds of our investors. It is a path we will consider.

Fortnightly: What market potential do you see for electric vehicles?

Eberhart: All cars will be electric eventually. It's only a matter of when. In 20 years they will be the predominant vehicles people buy.

This will happen because the technology is becoming radically more efficient, and our ability to make cars cheaply will get better with time. Already we can go 250 miles, and [fuel] cells are increasing capacity by 8 percent per year. The efficiency doubles every 10 years—like a slow Moore's law. In 10 years, the power plant will be smaller than an equivalent gasoline-powered engine. It will go 400 to 500 miles on a charge and it will last at least 100,000 miles. In 20 years, it will be a no-brainer.

It also will happen because electric cars are the ultimate multi-fuel vehicle. We generate electricity with all kinds of different fuels. With electric cars, the country will be free to adapt its energy supply.

Fortnightly: I hear about new developments in battery technology every week. Your vehicle is using thousands of small lithium-ion batteries, like the ones in camcorders. Do you expect to use larger batteries when the technology advances?

Eberhart: Our strategy is to use >>



“Power companies have an opportunity to become a major player in the world of transportation.”

— Martin Eberhart, Tesla Motors CEO

the best commercially available cells, but the trick is to use a massive number of small cells. That is the crazy idea we are using here, for many reasons that aren't crazy at all. For example, with lots of small cells, you get a massive surface area that helps to keep them cool and happy.

Big cells are a mistake. If a company comes along and says "We have these big batteries," we say "No, thank you."

Fortnightly: What role would you like to see utilities play in developing the electric transportation market?

Eberhart: Power companies have an opportunity to become a major player in the world of transportation, and some of them realize it. We are getting a lot of interest from utilities. Based on conversations I've had with PG&E, they really understand the vehicle-to-grid (V2G) concept. There's a measurable value to having storage capacity available in vehicles plugged into the grid.

Utilities can help in a lot of ways. One practical issue is to rationalize rate structures so the same rate works for both solar roofs and electric cars. There is a lot of synergy between them.

Also utilities should take ownership of charging standards. They should promote all the necessary standards and infrastructure for V2G, and tell me what standards I should be using. That's the only way it can happen, because it will depend on metering and billing.

Our customers would love it if we could work with power companies to offer programs that allow a customer to pay in advance for green generating capacity, to fund construction of new solar or other generation. But it shouldn't be any fuzzy carbon-offset crap. It should be attached in some way to generating capacity.

The magic in making it appealing is in billing. The bright marketing minds at power companies can do this.

Fortnightly: Who is going to buy these cars? Most people won't pay more—or at least not much more—for environmental benefits.

Eberhart: Let me clarify. People care about oil conservation for two reasons: because of the environment, and just as much because of national security. People realize this oil situation is really screwed up.

That is becoming a new conservative position, by the way. People who care are more than just greens.

But to address the point, we are mainly selling to people who care enough to spend a lot of money on it. They will create the market for our next car. The White Star won't be cheap, but it will be much cheaper than the Roadster. We will build tens of thousands of them, which is puny compared to the big automakers. But it enables my next car, which will be cheaper and we'll build many more of them. You see?

Fortnightly: Are you advocating policy changes?

Eberhart: Yes, a whole bunch of them, mainly tactical. For example, today there's an income-tax credit for hybrids, but the electric-vehicle credit expired because of neglect. And it's ridiculous now that you can get a tax credit for buying a Hummer. We'd like to see a level playing field, thank you very much.

Fortnightly: What about metering policies? They are changing in many states. What would you like to see regulators and utilities do in terms of metering infrastructure and policies?

Eberhart: Advanced metering is an opportunity for power companies to really help the electric-car and solar industries. The ability to shut off the power remotely, so the lineman can install solar panels, would be very helpful. And net metering and time-of-use rates are good for everyone.

Power companies are in a great position to tie everything together—me and other EV people, and plug-in hybrids, and solar and other clean generation sources—all together in a coherent system. Power companies have the opportunity to play a really major role, and become bigger than they are now.

We are very interested in talking and working with power companies to make it happen. We are small, but we are very interested in promoting cooperation. ■

Electric & Hybrid Cars

(Cont. from p. 33)

question has to do with costs. Calculating the cost of providing these services includes both fixed and variable costs. The fixed costs include the additional cost to provide V2G functionality to a PHEV and the communication and control equipment necessary to allow remote dispatching of an aggregated fleet of PHEVs. The additional cost to allow V2G on the vehicle side should be minimal given that PHEVs will have most of the necessary power electronics onboard. The cost of a system to allow communication and control between the grid operator and a fleet of V2G PHEVs is yet unknown, but

given the rapid development and reduced costs of these technologies we expect that this—when amortized over a fleet of tens of thousands of vehicles—would be minimal.

The variable costs resulting from PHEVs providing these services is a function of the energy throughput and the associated cost of battery degradation. We are confident that the variable cost of providing spinning reserves would be minimal, as these services rarely are used and when they are dispatched, it typically occurs for just several minutes. Using the experience of PJM given above, spinning reserves were deployed for only 21 hours during the entire year in 2005. Thus, in the case of a PHEV providing 10 kW of spinning reserves, assuming they

were dispatched for every event during the year, it translates into total energy throughput of 210 kWh of energy. It is likely that this level of energy throughput would contribute little to overall battery degradation. In contrast, regulation reserves would require short and frequent charging and discharging of the onboard battery pack. Given limited knowledge of how the next generation battery technology likely to find its way into PHEVs would be affected by this type of cycling, we are unable to provide an estimate of potential battery degradation from providing this service.

Windfall or Headache?

PHEVs represent an exciting opportunity to create greater energy independence and at the same time reduce harmful emissions. Furthermore, as the electric-supply mix becomes greener, this affords additional environmental benefits as the vehicle fleet becomes increasingly reliant on electricity as a form of energy for transportation.

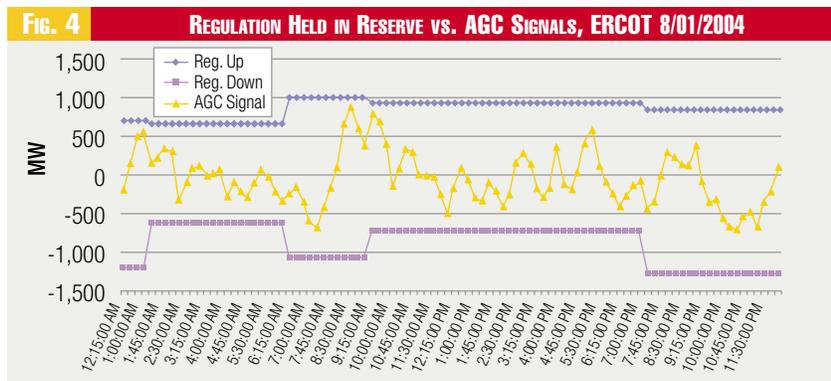
We believe that PHEVs represent an historic business opportunity for the electric utility industry that is not yet fully appreciated. Rarely in history has an emerging technology offered such an attractive opportunity for the industry, as both a new load and resource, to enhance overall performance of the electric-power infrastructure.

Are there challenges to realizing the vision? Yes. But the time is now for the industry to take a serious look at the PHEV potential. We believe that the evidence is sufficiently compelling that the industry should lend its voice to a growing chorus of stakeholders calling for the major auto manufacturers to deliver a commercial PHEV to the market, begin V2G demonstrations, and develop business models that could serve to efficiently and profitably exploit the emerging V2G potential. **E**

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