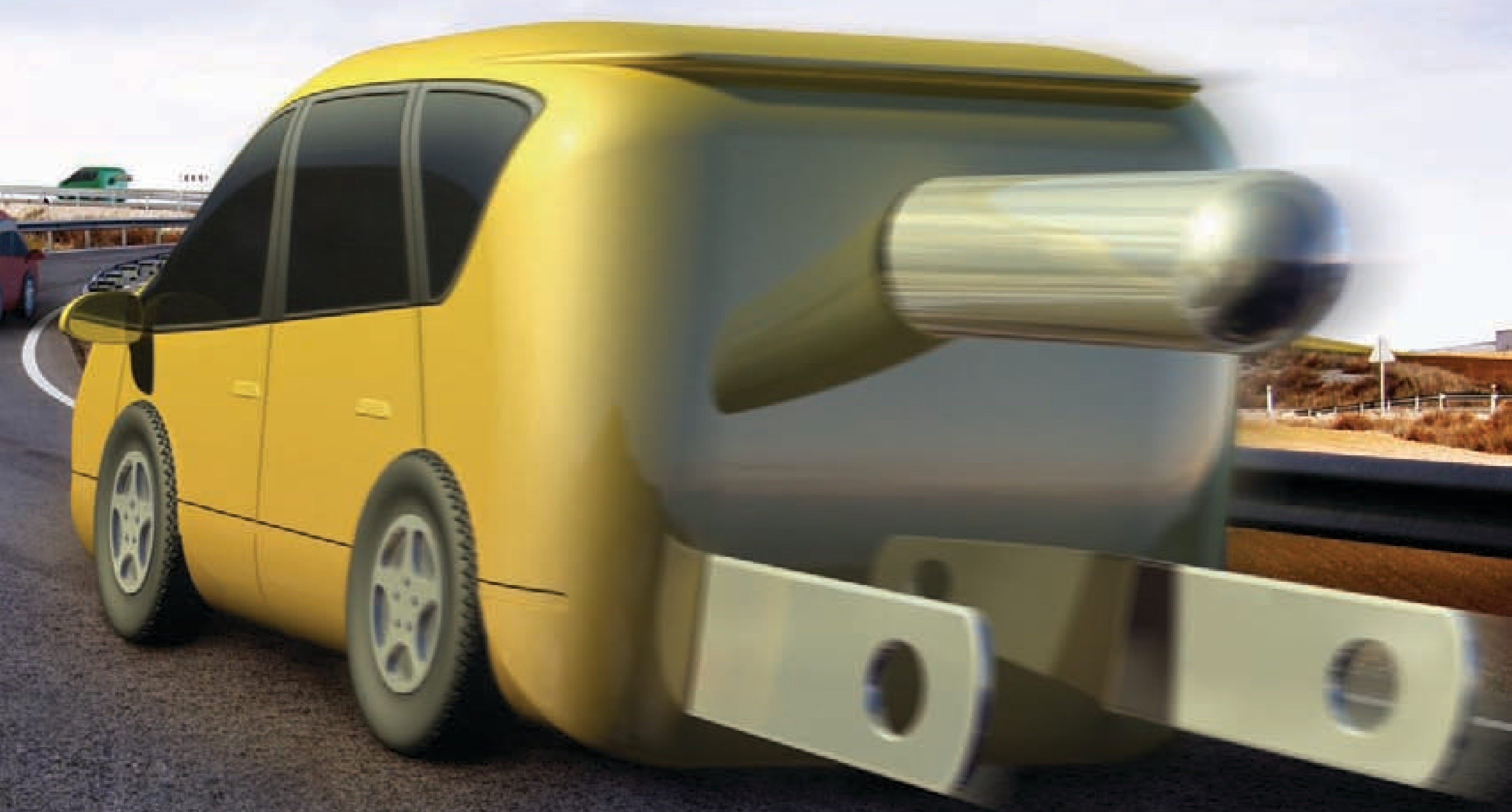
Plug-In Hybrids

on the Horizon

Building a Business Case



The Story in Brief

Automakers, utilities, and the public are increasingly interested in plug-in hybrid electric vehicles. Recent EPRI studies indicate that society could realize significant benefits to the environment and the economy with PHEVs. EPRI studies also point to sizable challenges and opportunities in technology and utility operations. What's needed is research and development in batteries, the power grid, and generation technologies—and a market that's ready to put substantial numbers of drivers behind the wheel of a PHEV.

Consider these three aspects of electric transportation: It potentially offers consumers a lower-cost alternative to gasoline. It decreases greenhouse gas emissions from the transportation sector. And it reduces dependence on imported petroleum.

Plug-in hybrid electric vehicles (PHEVs) represent the most promising approach to introducing the significant use of electricity as transportation fuel. Unlike battery-only electric vehicles (EVs), PHEVs do not require on-demand, high-power recharging. If the driver misses a charge, the vehicle can run seamlessly on gasoline in hybrid mode until charging is again convenient. While the battery is smaller and less costly for a PHEV than for an EV, the battery is more deeply discharged each day, so many drivers will use as much or more electricity with a PHEV.

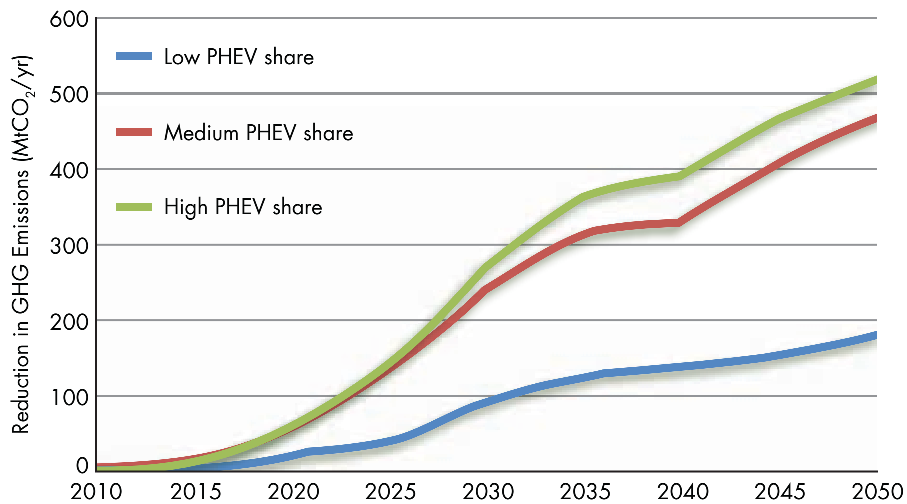
PHEV development can build on more than a decade of experience with conventional hybrids such as the Toyota Prius and Ford Escape, which use a battery and electric motor to augment the power of an internal combustion engine. To this blend of technologies, PHEVs add the ability to charge the battery using low-cost, off-peak electricity from the grid—allowing a vehicle to run on the equivalent of 75¢ per gallon or better at today's electricity prices. A benefit for utilities is that PHEVs draw only about 1.4–2 kW of power while charging—about what a dishwasher draws.

The primary challenges to widespread use of PHEVs, challenges that will require direct utility involvement to overcome, include specification of a convenient grid interface, creation of a two-way communication system to potentially enhance cost savings, and development of a mass market to lower battery costs.

Environmental Benefits of PHEVs

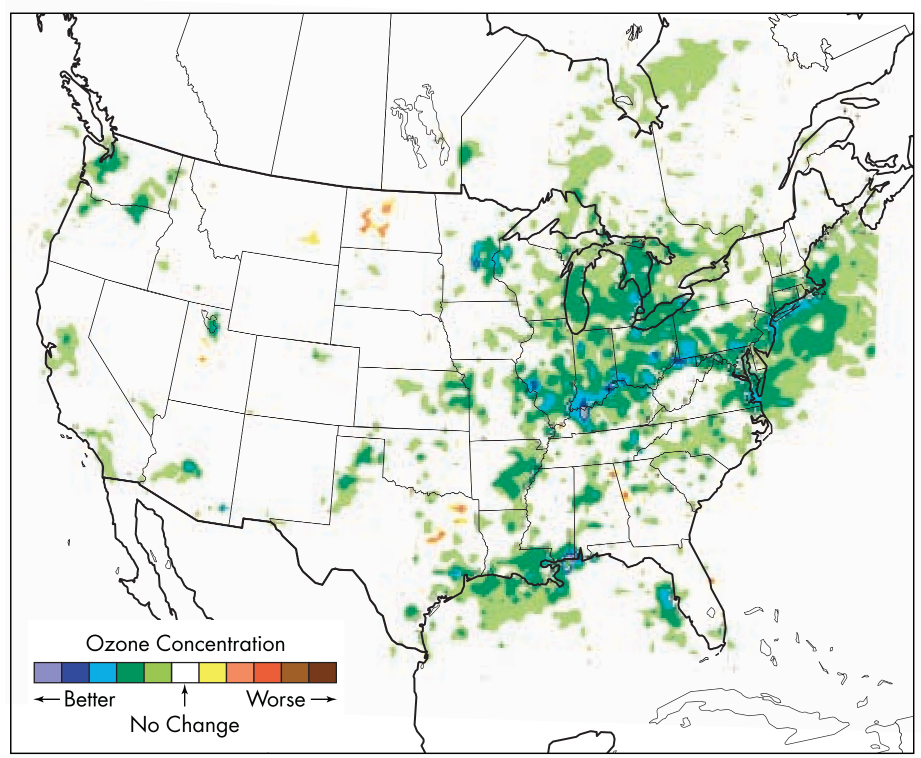
One possible stumbling block to widespread public acceptance of PHEVs is the lingering question about whether charging vehicles with electricity from the grid will just reduce one source of pollution

Annual Greenhouse Gas Emissions Reductions From PHEV Adoption



EPRI studies indicate that putting PHEVs on the road could reduce U.S. greenhouse gas emissions by as much as 500 million metric tons a year by 2050. By that time, cumulative reductions are expected to total 3.4–10.3 billion metric tons, depending on PHEV market share and several other factors.

PHEV Improvement in Ozone Concentration



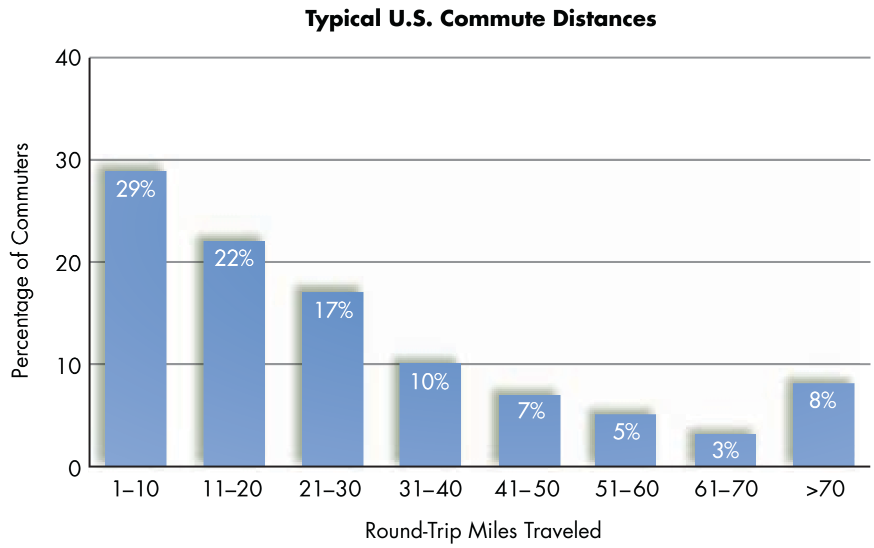
In addition to reducing greenhouse gas emissions, PHEV adoption is expected to help reduce emissions of other air pollutants as well, including volatile organic compounds, nitrogen oxides, sulfur dioxide, ozone, and particulates. Reductions in ozone emissions are particularly impressive, with improvements expected in most regions.

(gasoline) and substitute another (power plants). EPRI recently examined this question in the most comprehensive environmental assessment of electric transportation to date. Conducted with the Natural Resources Defense Council (NRDC), the assessment focuses on the likely environmental impacts of bringing a large number of PHEVs onto American roads over the next half century.

The first part of the study used a scenario-based modeling analysis to determine how PHEVs would change U.S. greenhouse gas (GHG) emissions between 2010 and 2050 under various circumstances. This inclusive "well to wheels" analysis tracked emissions from the generation of electricity to the charging of PHEV batteries and from the production of motor fuels to their consumption in internal combustion vehicles. Researchers used detailed models of the U.S. electricity and transportation sectors to create a range of potential scenarios and changes in both sectors. The three scenarios for the electricity sector represented high, medium, and low levels of carbon dioxide (CO_2) and total greenhouse gas emissions, as determined by the projected mix of generation technologies and other factors. For the transportation sector, the three scenarios represented high, medium, and low market penetration of PHEVs from 2010 to 2050.

Results were unambiguous: GHG emissions were reduced significantly over the nine scenario combinations. The cumulative GHG emissions reduction by 2050 was at least 3.4 billion metric tons (Gt), assuming a persistently high level of CO_2 intensity in the electricity sector and a low level of PHEV fleet penetration. Assuming low CO_2 intensity and a high level of fleet penetration, the cumulative GHG reduction was 10.3 Gt. Reductions were realized for each region of the country.

The second part of the study focused on determining the effect of aggressive PHEV fleet penetration on overall air quality in a single year, 2030. It compared a base case that assumes no PHEV penetration with an aggressive penetration case in which PHEVs achieve 50% of new-vehicle sales and constitute 40% of on-road vehicles by 2030. First, a variety of important emissions were modeled for the transportation and electricity sectors and then merged with emissions from all other sectors. Using these data, key air quality indicators were calculated by means of the U.S. Environmental Protection Agency's Community Multi-scale Air Quality (CMAQ) model.



Data from the U.S. Bureau of Transportation show that 78% of commuters travel 40 miles or less each day—the expected battery-only range of PHEVs with routine overnight charging. For longer distances, the vehicles could run indefinitely in hybrid (gasoline/electric) mode.

This analysis found that, for most regions of the United States, increased PHEV use would result in "modest but significant improvements in ambient air quality and reduction in deposition of various pollutants." Considering the electricity and transportation sectors together, PHEVs would help reduce emissions of volatile organic compounds, nitrogen oxides, and sulfur dioxide. Ozone levels would decrease substantially for most regions, although there would be very minor increases in some local areas. Ambient levels of particulate matter would also decrease in most regions.

"These studies should put an end to the myth that electrification of the transportation sector would increase pollution," says Mark Duvall, manager of technology development for EPRI's Electric Transportation program. "Even in the worst-case scenario, assuming only limited introduction of new power plant technology, we see an overall reduction in emissions related to both air quality and global warming."

Economic Benefits of PHEVs

In another study, EPRI assessed regional economic benefits associated with increased market penetration of plug-in hybrids. The underlying context for this study is the increasing involvement of municipalities in policy areas, such as economic development and environmental protection, that were previously regulated only at the state or federal level. Other studies have examined microeconomic benefits of PHEVs or estimated macroeconomic impacts for the entire United States; this assessment was distinct in calculating expected regional financial and labor impacts resulting from a transition to PHEVs.

This approach can explore in more detail the economic multiplier effect of petroleum displacement. Because the per-mile cost of operating a vehicle on electricity is currently about one-quarter to one-third the cost of using gasoline, vehicle owners can anticipate spending less for transportation. Such savings also represent a transfer

Batteries on the Critical Path

Much enthusiasm for PHEVs is based on the expectation that lithium ion (Li-Ion) batteries can make the leap from electronic devices and small power tools to the much larger application of running a car. Skeptics question whether durable, affordable Li-Ion batteries will be available in sufficient numbers to launch a major automotive revolution within the proposed two- to three-year period. Toyota is making its initial PHEVs with a nickel–metal hydride (NiMH) battery similar to that in its standard Prius vehicle, citing uncertainty about when Li-Ion batteries will be ready for full-scale production. NiMH batteries are not expected to be a widespread choice for PHEV applications because of their low energy density.

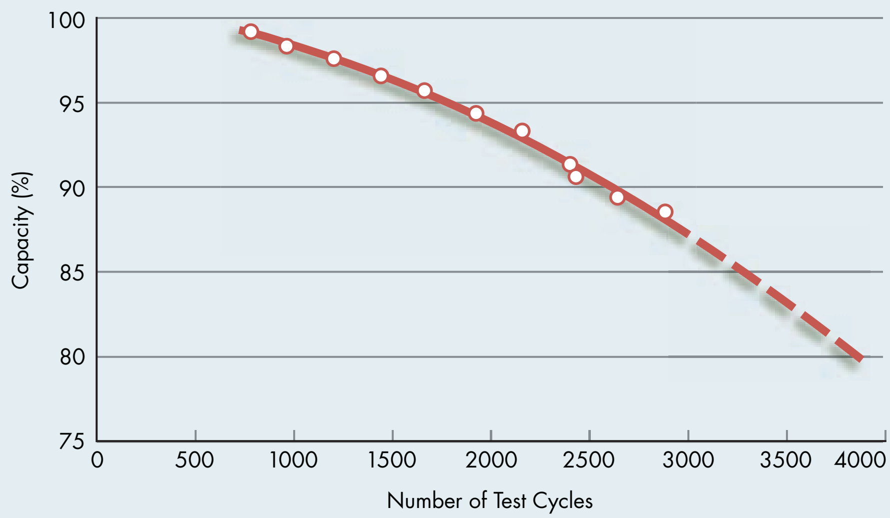
The California Air Resources Board (CARB) recently examined a variety of technologies related to the development of zero-emission vehicles. The report noted that although NiMH technology in today's hybrid electric vehicles could probably be modified to meet the technical needs of PHEVs, no substantial efforts appear to be under way to develop NiMH batteries for this application in the long term. Rather, the report concluded, Li-Ion batteries are "making impressive technical progress worldwide," especially with regard to longevity, cycling durability, and safety.

The CARB study projected PHEV introduction at the precommercial level (thousands of units per year) by around 2010, with commercialization (tens of thousands of units per year) by 2015. In contrast, the study concluded that fuel cell electric vehicles running on hydrogen would not be commercialized until about 2020, in part because of the need to establish a new fuel distribution infrastructure.

The main advantage of Li-Ion batteries is that they weigh less than NiMH batteries for the same level of performance. Manufacturing costs for Li-Ion batteries are higher but are expected to fall sharply with improvements in design and manufacturing and with mass production. Also, the cost of nickel is rising rapidly, while lithium is relatively abundant and inexpensive. Although any battery system has safety issues, the overheating concerns associated with the Li-Ion batteries used in laptop computers are not directly applicable to the batteries used in automotive applications, which are made with different electrode materials.

EPRI, working with Southern California Edison, began studying the effect of the PHEV duty cycle on the best available Li-Ion battery technologies nearly three years ago. To date, the first test pack has completed over 3000 dynamic deep-discharge PHEV cycles in the laboratory while still meeting the necessary power and energy requirements.

Lithium-Ion Battery Life-Cycle Testing



Battery durability testing sponsored jointly by EPRI and Southern California Edison demonstrate that current lithium-ion batteries are likely to retain sufficient capacity for more than 3000 dynamic deep-discharge cycles—about 10–12 years of typical driving.

into the local economy of funds that would otherwise have been spent on imported petroleum—an effective boost in regional economic activity and job growth. A 2002 study by the U.S. Department of Energy estimated that if only 1% of American vehicles ran on electricity in 2010, the national economic benefit would be about $1.46 billion (in 1999 dollars)—a benefit far greater than the value of the petroleum displaced—and that 14,000 new jobs would be created.

To examine this effect more closely, the EPRI study sought to quantify the regional economic impacts of significant PHEV market penetration (50% of new-car sales and 40% of all on-road vehicles) in 2030. Six major urban areas were studied: Cleveland, Austin, Birmingham, Kansas City, Newark, and Sacramento. Because actual impacts will vary with changing energy prices, four scenarios used widely different price levels for electricity and gasoline. In addition, two scenarios modeled the economic multiplier effect: in one, displacement of gasoline reduces the demand for *all* industries that support a region's petroleum market, and in the other, demand reduction will *not* affect a region's petroleum refining industry. The researchers note that the former scenario represents worst-case assumptions and that the latter scenario is more realistic, since regional refineries could probably continue to sell their products in the national market.

The results are complex, but in all cases, substantial increases in household incomes were projected from a transition to PHEVs —increases ranging from a low of $188.7 million/year in the Birmingham region, under the lowest energy price assumptions, to a high of $721.4 million/year for Kan-

Several major auto manufacturers have announced plans to introduce PHEVs in the near future. GM is developing its Chevrolet Volt concept car and the Saturn Vue Greenline SUV, which may hit the market in 2010. Ford is providing Southern California Edison with modified Escape Hybrid SUVs to demonstrate PHEVs as part of an integrated grid-connected system. Meanwhile, Toyota is testing a plug-in version of the popular Prius hybrid.

Saturn Vue Greenline SUV

Ford Escape Hybrid SUV

Chevrolet Volt Concept Car

sas City, assuming the highest energy prices. Regional economic output also increases in all cases because of the multiplier effect. Regional employment increases in all cases in which high energy prices are assumed but decreases in some regions if low energy prices are assumed.

The report concludes that "the potential local economic impacts from PHEV use are substantial" and that "policies that encourage PHEV use in any of the six cities could have significant regional economic payback." If anything, this study may underestimate potential benefits, since it does not consider the additional revenue that could be generated for both vehicle owners and utilities by using PHEVs connected to the grid to provide power management services.

PHEV Value Proposition for Utilities

Additional revenue streams projected for utilities consist of several distinct components, some of which will depend on utilities' undertaking marketing and infrastructure development initiatives in the near future. Increased sales can be expected as PHEV owners recharge batteries, but the magnitude of this increase will depend on several factors, such as rates that encourage charging during off-peak hours.

Such initiatives will also be essential to realizing the potential benefits of load-leveling, giving utilities an important opportunity to operate their systems more efficiently by encouraging vehicle owners to recharge batteries off-peak. With off-peak charging, the grid could support a high level of PHEV penetration without the need for more generating capacity, and utilities could improve power system efficiency.

EPRI, Ford, and SCE Collaborate on PHEV Integration

In March, EPRI and Ford Motor Company announced a three-year agreement to develop and evaluate technical approaches for integrating plug-in hybrid electric vehicles into the nation's electricity grid—a key requirement for facilitating widespread adoption of the vehicles. To pursue this work, EPRI is putting together a collaborative of utilities in the New York–New Jersey area that will test Ford Escape PHEVs. Subsequent trials will be conducted with customers of the participating utilities.

The new program will build on an ongoing partnership between Ford and Southern California Edison (SCE) to test 20 Escape PHEVs in the Los Angeles area. The new EPRI-Ford agreement will expand the evaluation and demonstration program to include other utilities and will help determine regional differences in how the operation of PHEVs will impact the electricity grid.

"This partnership represents a concerted effort by the transportation and electricity sectors to work together in advancing PHEV technology," says EPRI's Mark Duvall. "This effort should accelerate the pace of PHEV development while enabling the utility industry to prepare for the introduction of these vehicles."

Nancy Gioia, director of sustainable mobility technologies at Ford, agrees. "PHEVs have great promise," she says, "but they still face significant obstacles to commercialization, including battery costs and charging strategies. Ultimately such vehicles must provide real value to consumers. EPRI brings our collaborative efforts related to the potential of plug-in electric vehicle technology to a new level."

Research and analysis by EPRI, Ford, and SCE on the Ford PHEVs will include data from four primary areas: battery technology, vehicle systems, customer usage, and grid infrastructure. The analysis will also explore possible stationary and secondary uses for advanced batteries. The evaluation and demonstration trials are expected to provide solid technical information on PHEVs that will enable the development of common standards among utilities to accommodate the vehicles.

Making this transition will require new rate incentives or direct-control systems.

Finally, the prospect of carbon emissions legislation offers a definite—though highly uncertain and somewhat controversial—possibility for utilities to achieve additional revenue from rising PHEV penetration. In January of 2007, California's governor established a low-carbon fuel standard (LCFS) for the state by executive order. The order essentially directed various state agencies to develop protocols for measuring the "life-cycle carbon intensity" of transportation fuels and to develop a regulatory process to meet a 2020 target of reducing the carbon intensity of transportation fuels in California by 10%. University of California studies found this target to be "ambitious but attainable" and recommended that the providers of non-liquid fuels—specifically electricity—be allowed to participate.

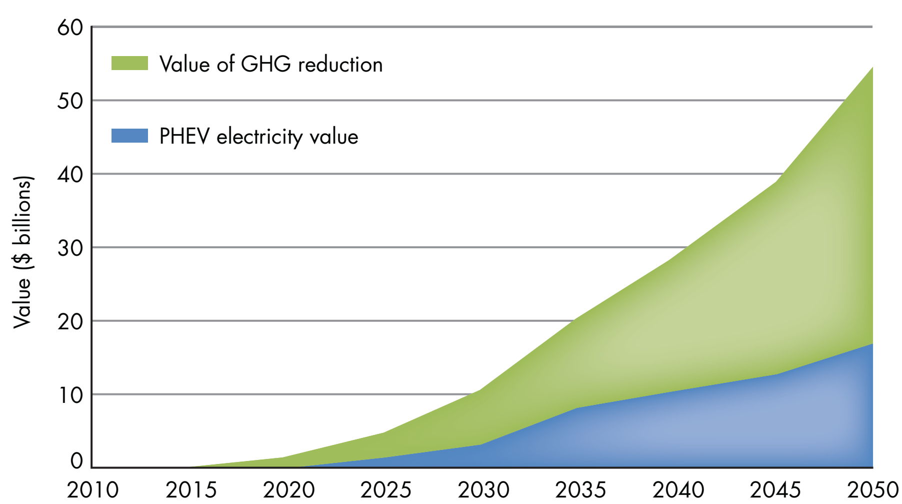
Although the LCFS regulatory process is not yet final, the implications for utilities may be profound, particularly if other states adopt similar standards. As an illustration, suppose a future LCFS should limit the carbon content of vehicle fuel to the equivalent of 8 kilograms per gallon (kg/gal), compared with the approximately 10 kg/gal of today's gasoline. A PHEV could achieve this decrease, and—assuming a tradable carbon value of 20¢ per gallon—the reduction could potentially add 2¢ per kilowatt-hour to the value of electricity. How utilities would realize this added value, however, remains to be seen.

Auto Industry Interest

The theoretical advantages of PHEVs have long been recognized; limited numbers were manufactured more than a century ago, and another attempt to introduce the concept was made in the 1960s. Until recently, conventional batteries were simply too large, too heavy, and too limited in performance to produce a commercially competitive vehicle. Now, with rapid development of lighter, more durable batteries (see "Batteries on the Critical Path," page 10), several major manufacturers have announced plans to introduce PHEVs over the next two years.

Toyota Motor Corporation claims to be the first automaker to have a PHEV certified for use on highways, in Japan, and is planning a series of tests in Europe and the United States as well. Toyota is gaining experience by using a modified version of its Prius hybrid, with nickel–metal hydride (NiMH) batteries, but will probably switch to lighter lithium-ion (Li-Ion) batteries as

Potential Value of PHEV Adoption



If greenhouse gas emissions become regulated in the future, the value of PHEVs in reducing GHG emissions may end up being twice that of increased electricity sales, although it is not clear how this value would be shared among power providers, shareholders, government, and customers.

they become available. A small aftermarket has arisen to convert existing Prius cars to PHEV operation, although Toyota does not support this activity.

A major psychological breakthrough for the PHEV market occurred when General Motors introduced its Chevrolet Volt electric concept car at the 2007 North American International Auto Show, claiming that it "could nearly eliminate trips to the gas station." According to GM, the Volt can be fully charged from a standard electrical outlet in about 6 hours and deliver 40 miles of city driving from its Li-Ion battery. When the battery's charge is depleted, a three-cylinder engine recharges the battery and runs the car's electric motor—achieving a gasoline conversion efficiency of about 50 miles per gallon. If the Li-Ion battery is ready, GM plans to market the Volt by 2010. The company also plans to market a PHEV version of its Saturn Vue Greenline sport utility vehicle.

Meanwhile, EPRI, Ford Motor Company, and Edison International—parent company of Southern California Edison (SCE)—have announced a joint program to demonstrate PHEVs as part of an integrated system involving the vehicle, home energy systems, and the electricity grid (see "EPRI, Ford, and SCE Collaborate on PHEV Integration," page 12). The program will evaluate potential benefits of using off-peak electricity to reduce costs per mile while increasing grid productivity and reducing emissions of carbon dioxide and pollutants. Eventually, PHEVs might also be considered for use as home-based energy storage units for solar power generated by rooftop collectors or as a source of stored power that could be tapped as needed by the utility. A modified Ford Escape Hybrid SUV will provide the PHEV platform for the SCE program.

EPRI is currently leading a broad, inter-industry program to develop a PHEV "trouble truck" with an aerial lift for servicing utility distribution systems. Program funders include 36 utilities and two California public agencies. Eaton Corporation is developing the hybrid system on

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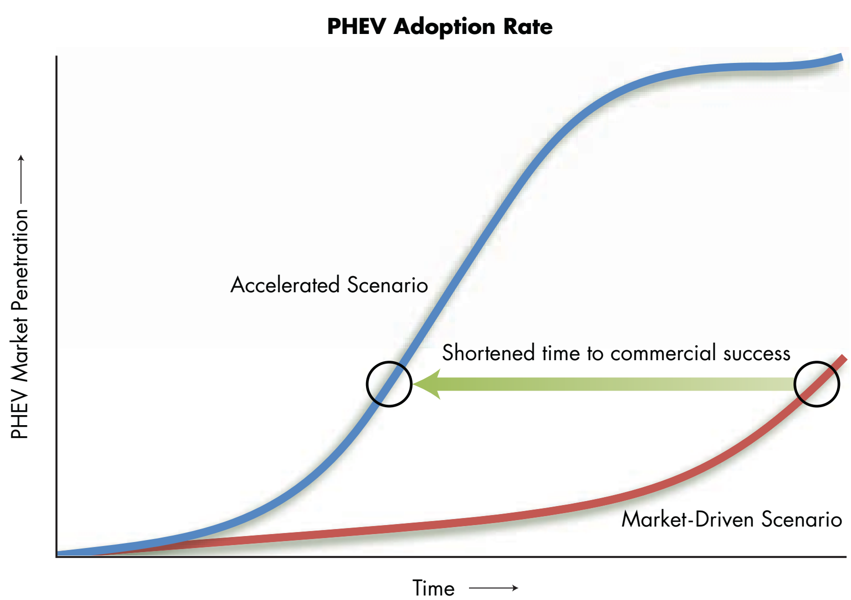


Market penetration of new automobile technologies tends to grow slowly because of high initial cost and first-of-its-kind risk to early adopters. The involvement of power providers and other stakeholders outside the auto industry can help PHEVs reach higher penetration faster by providing purchase incentives, special PHEV electricity rates, advanced infrastructure options, and consumer education.

Ask the Expert

An interview with Mark Duvall, manager of technology development for EPRI's Electric Transportation program.

Q. There appears to be enormous interest in plug-in hybrid technology. What are the prospects for these vehicles to reach the market by 2010?

A. Plug-in hybrid development is at a crossroads. The technology currently has tremendous momentum, with GM, Ford, Toyota, and others vying to be either first to market or "best to market." The forces driving this interest—pressures to reduce petroleum dependency and the high cost of fuel and to address climate change—all point in the direction of PHEV technology. However, it is important to remember that most transformational automotive technologies fail—often spectacularly, and many times when the technology is right on the cusp of commercial viability.

Why is utility involvement in PHEV commercialization important?

PHEVs are transformational in that they introduce electricity as a meaningful automotive fuel to a potentially very large market. The utilities could have much to gain from a massive shift of cars to PHEV technology, but the success of this transition will depend heavily on their involvement.

What benefits could utilities expect to receive from participating in PHEV penetration of the auto fleet?

The utility value proposition for PHEVs is large and complex. PHEVs, at a minimum, provide predominantly off-peak load—allowing utilities to improve system efficiency and asset utilization. In the long term, however, the potential is much greater. Electricity is a low-carbon, clean transportation fuel, and as utilities increasingly provide electricity as a transportation fuel, their service territories will realize benefits in air quality and reduction of greenhouse gas emissions. PHEVs also represent a storage resource that could be managed to optimally suit a utility's load profile.

But won't major infrastructure changes be required?

It is important to recognize that the market share of PHEVs in the nationwide automotive fleet will grow slowly over time and that the individual load of each vehicle is small. As market share grows, utilities may have to be on the lookout for local impacts, but this is a normal part of their business. Ultimately, if PHEVs succeed, electric utilities will become refueling stations for their customers. Utilities can strengthen their credentials as good environmental stewards and improve customer satisfaction by proactively addressing this new technology.

How sure are you regarding the environmental benefits of PHEVs?

We just completed a comprehensive nationwide air quality and greenhouse gas assessment, in cooperation with the Natural Resources Defense Council. We used the most sophisticated modeling tools available in order to understand, as closely as possible, what the electricity system's response to PHEVs will be in terms of which plants will be dispatched to generate the charging energy, what the net changes to emissions will be in the electricity and transportation sectors, and how the emissions will react chemically in the atmosphere to affect air quality. Even using what we would very much consider to be a worst-case scenario, we found near universal air quality benefits nationwide. This is not an unexpected result, given the maturity of the electricity sector, its closely regulated nature, and declining emissions intensity in the face of increased regulatory requirements.

What about greenhouse gas emissions? There seems to be a lot of debate on this issue.

Under nearly any foreseeable scenario, electricity is a low-carbon fuel, compared with gasoline and diesel. A PHEV charged by the most carbon-intensive generating plants is essentially equal to a conventional hybrid in terms of total greenhouse gas emissions. When you actually look at utilities' responses with respect to new generation, the increased regional requirements for renewables, and expected responses to future carbon constraints, the GHG reductions are considerable.

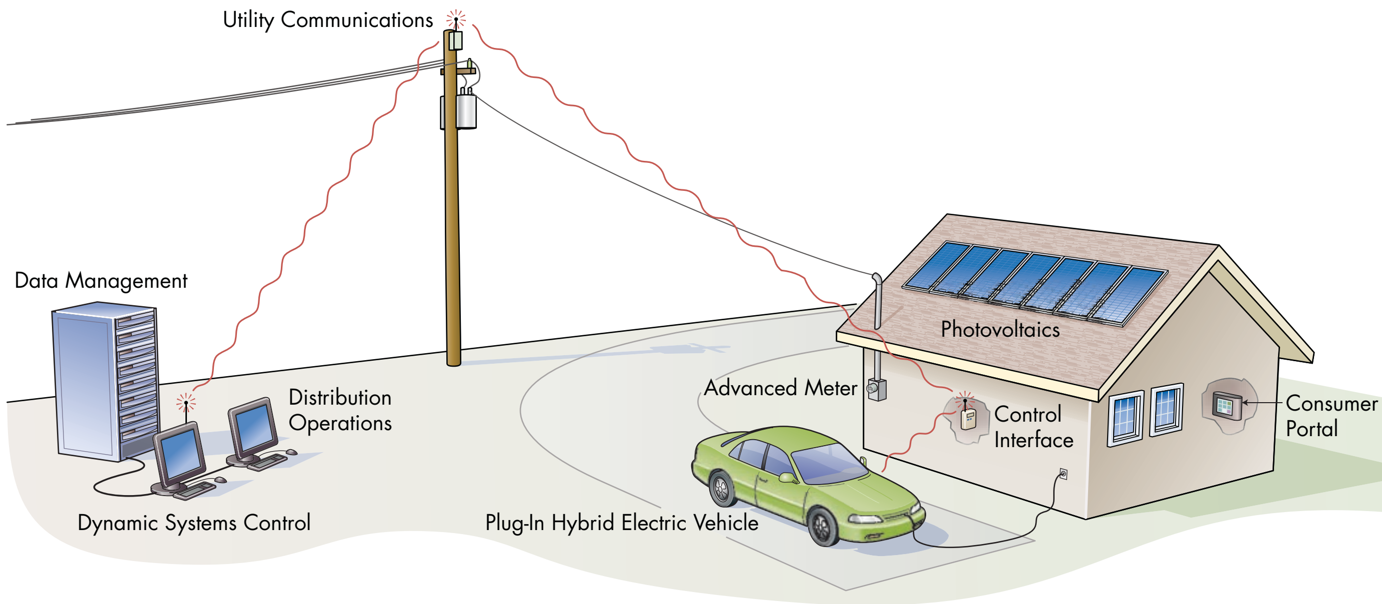
What should utilities do next, and how can EPRI help?

Utilities should consider joining existing EPRI–automotive industry collaborations. These provide opportunities for vehicle manufacturers and fuel providers (electric utilities) to work closely together on the issue, which can help drive successful commercialization of this important technology. Utilities will have the earliest possible access to prototype vehicles, enabling them to get first-hand experience with the performance of the vehicles in real-world driving and—more important—with the interaction between the vehicles and their systems.

a Ford F550 chassis and will conduct vehicle testing and calibration. Five prototype vehicles—two with diesel engines and three with gasoline engines—will be delivered for utility fleet demonstration, beginning this year.

The choice of a trouble truck as a PHEV test vehicle offers several advantages to utilities, including hands-on experience with the new technology. In addition to reducing fuel consumption and emissions, the truck will be able to provide 6 to 8 hours of standby work time with zero or minimal engine idling, minimizing impacts on neighborhoods and operators. Alternatively, when operated in a high-idle mode, it can generate up to 5 kW of ac power to provide grid services in the field. Once successfully demonstrated in utility use, the technology could be adapted for medium-duty vehicles in the 8500- to 19,500-pound weight classes. Such vehicles—including work trucks and vans, shuttle buses, and even medium-sized

Future Intelligent Infrastructure



With their large, deep-discharge batteries, PHEVs may eventually serve as distributed energy storage units that could support not only the home but the electricity grid as well. The smart infrastructure for such vehicle-to-grid setups would require advanced metering and two-way energy and information exchange, similar to that currently used in home photovoltaic electricity sales to utilities.

motor homes—cover an array of applications suitable for electrification.

Next Steps

EPRI can serve a crucial role in fostering collaboration between the automotive and electric power industries and in integrating PHEVs with the grid. EPRI is organizing a nationwide demonstration program to place early production prototype PHEVs into utility fleets. This effort involves General Motors, Ford, and various U.S. and Canadian utilities in developing critical information on the impacts of PHEVs on utility operations. Eventually utilities are expected to include some of their larger commercial customers in testing the vehicles and to create profiles of customer needs and preferences. EPRI will manage the demonstration program and coordinate data collection and analysis.

This program will also apply so-called smart grid concepts to help optimize the value of PHEVs for system operations. Smart meters will enable customers to charge vehicles when lower rates are in effect, and a two-way communication connection with the utility would permit further savings by providing remote control of the charging load. The concept of smart charging, which determines the best charging regime in real time, will also be given consideration. Utilities have a direct stake in uniform connection standards that meet the needs of all parties.

Over a longer period, PHEVs may provide the capabilities for load leveling and/or grid support. The vehicle-to-grid, or V2G, option faces substantial hurdles that will require long-range research to resolve. Although conceptually V2G is an example of distributed generation, in practice it differs from most small power sources, which are stationary and professionally operated. In addition, integrating this option into the grid would probably require significant infrastructure investment in order to protect against potential hazards and the possibility of degrading battery performance in the quest to obtain a still-uncertain economic payoff.

"Utilities want to *manage* the charging of PHEVs, which will involve gradual, evolutionary grid adaptation," says Mark Duvall. "But they need to *control* V2G, and that would require careful study and considerable expense. Meanwhile, we hope our new demonstration program will help develop a sustainable business case that can foster PHEV penetration of the North American vehicle fleet while benefiting both vehicle manufacturers and utilities."

This article was written by John Douglas. Background information was provided by Mark Duvall (mduvall@epri.com).

Mark Duvall is manager of EPRI's Electric Transportation program, focusing primarily on plug-in hybrid electric vehicle R&D and advanced battery system development and testing. Before coming to EPRI in 2001, he was principal development engineer at the Hybrid Electric Vehicle Center at the University of California at Davis. Duvall holds BS and MS degrees in mechanical engineering from UC Davis and a PhD in the same field from Purdue University.