POSITION STATEMENT

PLUG-IN ELECTRIC HYBRID VEHICLES

Adopted by the IEEE-USA
Board of Directors, 15 June 2007

Plug-in hybrid electric vehicles (PHEV) can contribute significantly to transportation system efficiency by introducing vehicles that, within a limited range, can operate entirely in an electric mode and be powered by the electricity grid. Conventional Hybrid Electric Vehicles (HEVs) are already starting to create great benefits to US energy including consumption and security. Based on EPA data, the most energy efficient existing hybrids cut gasoline consumption by around 40 percent compared with similar conventional cars. But PHEVs typically replace half of the remaining gasoline consumption with electricity (IEEE Spectrum, July 2005). Thus PHEVs could reduce the consumption of liquid fuels by at least 70 percent compared with conventional cars.

In addition to reducing gasoline consumption they have the potential to also reduce total energy expenses for the owner and the electric power industry. Existing commercial hybrid vehicles have proven to be successful components of the transportation system in the US and abroad. Plug-In Hybrid Electric Vehicles use grid-supplied electricity from diverse domestic energy sources such as renewables, coal and nuclear, and reduce the nation's demand for imported oil.

PHEVs can also make it easier to achieve the goal of fuel flexibility and alternative liquid fuels. Fuel flexibility is easier to incorporate in hybrid vehicles than in conventional vehicles as recent concept cars illustrate. After plug-in hybrid electric vehicles substantially reduce our nation's liquid fuel requirement in cars, it will become far easier for alternative liquid fuels to supply the remaining liquid fuel demand.

In order to advance the utilization of plug-in hybrid electric vehicles, the IEEE-USA recommends the following:

- Use plug-in hybrid electric vehicles to add resilience to our transportation fleet and increase energy independence.
- Increase and diversify research to improve batteries for the plug-in vehicles, including weight, size, cost, life and safety, and associated power electronics and controls.

- Utilize appropriate government incentives to encourage a greater adoption and penetration of plug-in electric hybrid vehicles.
- Encourage the introduction of sophisticated electricity metering and pricing by electric utilities that will permit the full realization of all the potential benefits of a sophisticated vehicle battery charging system.
- Promote research on the integration and impact of PHEV's on the electric grid and the development of industry consensus standards to realize their full potential benefits. IEEE stands ready to assist in this process.

This statement was developed by IEEE-USA's Energy Policy Committee, and represents the considered judgment of a group of U.S. IEEE members with expertise in the subject field. IEEE-USA is an organizational unit of The Institute of Electrical and Electronics Engineers, Inc., created in 1973 to advance the public good and promote the careers and public-policy interests of the more than 220,000 electrical, electronics, computer and software engineers who are U.S. members of the IEEE. The positions taken by IEEE-USA do not necessarily reflect the views of the IEEE or its other organizational units.

BACKGROUND

A plug-in hybrid electric vehicle (PHEV) is defined as any hybrid electric vehicle which contains at least: (1) a battery storage system of 4 Kwh or more, used to power the motion of the vehicle; (2) a means of recharging that battery system from an external source of electricity; and (3) an ability to drive at least ten miles in all-electric mode, and consume no gasoline. These are distinguished from hybrid cars mass-marketed today, which do not use any electricity from the grid. The official EPA mileage gives a good picture of how much gasoline they save, though certain kinds of drivers get worse fuel economy than that both for hybrid cars and for conventional cars. The EPA web site for this analysis is: http://www.fueleconomy.gov/feg/download.shtml.

Using 2006 data for otherwise identical models of hybrid and non-hybrid cars for SUVs and automobiles, the hybrid vehicles show better combined mileage between 20 percent and 47 percent better than the corresponding model. The Toyota Prius, at 47 percent, is currently the leader, but other manufacturers are catching up rapidly. The conventional vehicles in the data used for this analysis ranged from 21mpg to 31mpg. For 2007 data for SUVs and the few cars for which an identical model is available in non-hybrid, show an improvement of between 16 percent and 40 percent. The fleet of conventional vehicles in this analysis ranged also from 21mpg to 31mpg.

If one compares cars specifically designed as hybrids rather than adapted from conventional designs, the numbers get better but the comparisons become more difficult. It is probably safe to say that current technology conventional hybrid cars and SUVs deliver on average better than 30 percent mileage figures comparable to conventional cars, with the best state-of-the-art hybrids approaching 50 percent or better.

The national security benefits of reducing our dependence of foreign oil with a large reduction in US gasoline needs would be significant. If we assume a range of gasoline prices between $2.50 and $3.00/gallon for gasoline and a vehicle fleet that is driven between 12000 and 15000 miles per year, this, combined with the above estimates, the fuel savings per year range between $140 and $720 for the above assumptions.

Several car makers are moving quickly towards introducing plug-in hybrid cars, which would allow consumers to use electricity from the grid to replace gasoline, at their choice. The May 2005 issue of *IEEE Spectrum* gave some important information and the October 2006 and April 2007 issues of *Spectrum* have additional information. A Toyota Prius retrofitted with a larger than original 9kwh battery has an all-electric driving range of about 20 miles. On average, that replaces half of the (already reduced) gasoline requirement with electricity. Industry estimates suggest that the $3,000 cost differential between today's hybrids and similar gas-engine cars reflects the added costs of power electronics ($1200) and batteries ($1800). China now sells 10kwh batteries for $2000 for delivery October 2007, and it seems likely that new plug-ins will offer this big increase in gasoline-independence for little more cost than today's hybrids, but only from non-US manufacturers. It remains a challenge to help U.S. manufacturers keep up with the necessary R&D, so that the United States can keep pace on battery improvements, power chips and system integration issues. Irrespective of their source, however, battery technology improvements are rendering plug-in hybrids practical.

Using the above figures, if one were to assume that a plug-in hybrid with a range of 20 miles would be able to substitute half of its energy needs with electricity, the savings in gasoline consumption could be reduced by between 250-300 gallons per-car-per-year. Of course, this reduction in gasoline implies an increase in electricity consumption from the grid and the need to pay for the charging of the batteries.

The biggest benefit from plug-ins is security in case of a shortage, rather than gasoline saving per se. The ability to drive to work or shopping in case of a total gasoline shutdown or in case of a disruptive extreme gasoline price spike limits the possible economic damage of either event. This benefit requires, however, that cars be designed and deployed with this capability in mind. The current fleet of hybrid cars is rendered inoperable if the gasoline engine cannot be started, even if the (separate) starting battery of the car is discharged, or even when the battery that powers the electric motor is fully charged. Thus, criteria, regulations and design modifications will be necessary to take full advantage of this capability.

Several interesting web sites include various claims and much additional information on the options afforded by plug-in hybrids. While some of these sites are clearly for advocacy, they nevertheless contain a wealth of useful information and facts about these automobiles.[1] For instance, the claim that the electricity which replaces a gallon of gasoline would cost less than $1 is a credible number, and is supported by analysis. This claim is also credible when one realizes that using a small gasoline engine to generate electricity on-board a car is bound to be less efficient in fuel usage than a big 24-hour coal or nuclear base-load plant. When such plants are "on the margin" (typically at night or during off-peak electricity consumption hours) the cost of charging batteries using the electric grid is naturally more likely to be less expensive than the similar cost using the car's own gasoline engine. In addition to the merits of better

[1] See, e.g., http://www.hybridcars.com/blogs/power/ford-keen-interest-in-phevs, and http://www.iags.org/pih.htm

thermodynamic efficiencies that can only be attained in large-scale power plants, the cost per British thermal units (btu's) of coal or nuclear fuel is also a lot lower than the cost of gasoline, and is likely to remain so in the future.

It is useful to explore more than the potential advantages and disadvantages of a more complete integration of a plug-in hybrid fleet into the electricity grid. The simple view is to say that these vehicles would be charged at night, when the marginal units are the most efficient units in the system, and that because nighttime generally coincides with low demand times, it is likely that the use of these vehicles will impose no additional capacity requirements on the system. Such a simple view may be good for a simple viability analysis of the concept, but it must be expanded considerably and numerous additional questions need to be considered, both beneficial and detrimental, associated with large scale deployment of a plug-in hybrid vehicle fleet. In this statement we limit our attention to suggesting issues and proposing that additional studies will be needed to answer all these questions.

- The cost of producing electricity varies considerably both by time of day and location, and it is highly dependent on weather conditions and subject to disruptions in the system that can drastically affect in an instant the cost of providing electricity to any given location at any point in time. The deployment in many regions of the country of locational marginal prices in the wholesale market is the best indicator that such volatility is a natural and expected part of an electricity supply system. Thus, to render maximum benefit to society, the prices for electricity to be used to charge electric cars ought to reflect as much as possible the actual system conditions. In certain parts of the country all loads above a certain size are required to be on real-time prices. Perhaps this benefit can be extended to plug-in hybrids.

- Reserves and emergency load shedding are two important features that are essential for the power system to be able to work reliably. Plug-in hybrid electric vehicles are ideally positioned to provide this type of service if properly designed, integrated and given proper incentives to do so.

- The ability to regulate system frequency has diminished in recent years as a result of deregulation and the lack of sufficient incentives to provide regulation service in some sectors of the industry. If properly designed and integrated, plug-in hybrids have the opportunity to assist considerably in the provision of system frequency regulation.

- Beyond all of the above, plug-in hybrids have the inherent potential of acting as either stand-alone standby electricity generators, or, in the best of cases, act as fully interconnected emergency generators at the distribution level. Before such actions can take place, however, regulations and standards that would permit such a benefit would have to be developed.

- Currently, the IEEE has several standards and IEEE-USA has one position paper (http://www.ieeeusa.org/policy/positions/hybridelectric.html) that indirectly pertains to plug-in hybrids. However, a standard specifically addressing some of the needs of plug-in hybrid electric vehicles, if such a standard proves to be desirable, would be useful.

- All the points noted above will require more sophisticated controls and/or more sophisticated metering capabilities than are now in existence. As a result of advances in electronics, communications and computing capabilities, such an advanced sophisticated new metering and control system can most likely be developed at relative low cost.

- New sophisticated controls will be crucial to the cost and efficiency of plug-in cars themselves. For example, GM has stated that they already can obtain battery cells with sufficient power and energy density to mass-produce the Volt concept car, but face a challenge in the large-scale dynamic distributed control challenge of managing many cells in parallel as part of a larger system. The Chinese battery company Thunder Sky ascribes part of their success with car-sized batteries to use of modern intelligent control, pioneered by the US IEEE community but not fully utilized as yet in cars.

- Several exciting new battery concepts have begun to emerge, offering potential breakthroughs, from the basic research community, crying out for an expansion, upgrading and coordination of high-risk research in this area both in universities and small businesses, above and beyond existing programs which focus on larger battery suppliers.

It is also useful to try to back this position paper with facts from actual deployed or announced vehicular technology. For example, the recently announced entirely electric Tesla automobile has an announced range of about 250 miles and is being sold commercially. Some of the facts and figures that we use on our analysis are based on information available on this automobile (refer, for example, to http://en.wikipedia.org/wiki/Tesla_Roadster). Other information in our analysis is based on information available from the Department of Energy. (See, for example, Federal Register, Vol. 65, No. 113, Monday, June 12, 2000, Rules and Regulations, Department of Energy, Office of Energy Efficiency and Renewable Energy, 10 CFR Part 474, [Docket No. EE–RM–99–PEF], Electric and Hybrid Vehicle Research, Development, and Demonstration, Economy Calculation.)

An article in the December 2006 issue of *Public Utilities Fortnightly* highlights numerous additional potential benefits of plug-in hybrid and entirely electric technologies, particularly if these technologies are viewed as resources rather than merely loads. Acceptance of these technologies as a new grid resource will require rethinking many of our current assumptions about what is a load and what is a generator, and the proper implementation of pricing strategies within the grid.

Utilizing publicly available information, Table 1 provides a comparative analysis of the economics of operating a typical electric powered vehicle versus a conventional gasoline-powered vehicle.

Table 1: The economics of operating an electric powered vehicle against a conventional vehicle, based on data available for the Tesla, an electric powered vehicle scheduled for delivery in 2007.

Conventional Automobile		
Cost of gasoline	$2.50	$/gal
Fuel efficiency conventional car	30	MPG
Cost per 100 miles	$8.33	
Range (typical)	250	miles
Plug-in Hybrid Electric Vehicle		
Retail cost of electricity	0.11	$/KWh
Charging efficiency	86.00%	
Cost of energy in batteries	0.128	$/KWh
Electric efficiency (actual data)	0.11	KWh/km
Efficiency in miles	0.177	KWh/mi
Cost per 100 miles	$2.26	
Size of battery	44	KWh
Range of vehicle (calculated)	249	miles
Weight of Li-Ion batteries	650	Lb

In summary, conventional hybrids can cut fuel bills 15 to 50 percent compared to regular cars. Plug-in hybrids have the potential to cut gasoline consumption by at least 50 percent and more, in some cases. In addition to reducing gasoline consumption, plug-ins also have the potential to reduce total energy expenses for the owner. If properly designed, these cars can provide extra security, in that they will remain viable should a disruption of the gasoline supply system occurs. Even if there is no further progress in batteries beyond what China has attained to date, the added cost per vehicle for a credible plug-in hybrid could be brought to as low as $3500 per car compared with a comparable conventional car, which is not much more than a comparable conventional hybrid today. Finally, if plug-in hybrids are properly designed and integrated into the grid, they can help improve the operability and security of the electric grid itself, but this will require attention to how these vehicles are integrated into the grid.