Summary Report

Discussion Meeting on Plug-In Hybrid Electric Vehicles

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Executive Summary

Interest is growing in hybrid vehicles that can recharge from wall-plug energy because of their high fuel economy and the potential to reduce petroleum use. Therefore, the Office of FreedomCAR and Vehicle Technologies (OFCVT) convened a 2-day discussion meeting of over 120 experts representing the automotive and electric utility industries, national labs and academia to discuss technical and economic issues related to "plug-in" hybrid electric vehicles, or PHEVs. The U.S. Department of Energy (DOE) must ascertain whether the national benefits of PHEVs warrant support for R&D to make the vehicles cost-effective and to ensure that the electric power grid can supply the load.

DOE provided the attendees a 'white paper' distributed prior to the meeting containing technical background and provocative questions. In addition, government and private sector experts presented their perspectives in a plenary session. DOE then divided the participants into eight cross-functional groups and each group addressed the same questions – formulated to identify critical technical challenges (for the vehicle and electric power grid), customer expectations and the role of the Federal government. Though the groups deliberated independently, they arrived at many similar conclusions:

- The technical merits of PHEVs are clear – fuel economy can be improved substantially by either not using the engine (i.e., operating in an electric mode) or using it less (similar to today's hybrids, but allowing the battery to discharge throughout the day and recharge using off-peak electricity).
- The technical challenges of PHEVs are substantial – they can be built today, but current battery technology is a potential show stopper (energy, life and cost). Production and warranty costs would likely be unacceptable for manufacturers. The resulting purchase price (without incentives) and the risk of high operating costs (due to battery replacements) would probably be unacceptable for most customers.
- The technical merits of recharging with off-peak electric power are clear – overall power generation efficiency can be increased; the extent of environmental benefits/impacts depends on the specific power plant fuel source.
- The technical challenges for the electric power grid are manageable - the existing electric power distribution system is adequate to support the recharge demands of low volume deployment of PHEVs. Large numbers of vehicles with substantial electric range would likely require utility-controlled charging to ensure off-peak power use, maximize overall system efficiency and lessen the need for capacity beyond current demand growth projections. The technology to support vehicle-to-grid power discharge is doable, but infrastructure investment by utilities is required.
- Though there was debate, most agreed that fuel economy, rather than all-electric range (AER), is the key metric for mass market consumers. A specified AER drives costs up and reduces the likelihood of production. Characteristics such as convenience, performance, safety, durability and price must be competitive with conventional and hybrid vehicles in the marketplace.
- Participants expected the Federal government to set policy, support pre-competitive research, act as a trusted source of information (analysis, targets, standards, etc.) and minimize market barriers. In addition, many felt that economic incentives are appropriate for PHEVs.

Plenary Session Presentations

Mr. Ed Wall, Manager of OFVCT, kicked off the session by clarifying the objectives of the meeting and presenting recent survey data regarding consumer awareness of PHEVs. Conducted earlier this year, the survey indicated that over 70% of consumers are aware of plug-in hybrids, over half think they would be a good idea for their household and about one-third park their vehicles in garages or carports (i.e., where outlets are available or could be installed).

The DOE perspective continued with remarks by Mr. David Garman, DOE Under Secretary for Energy, who stressed the importance of the activity and reiterated the message of the Advanced Energy Initiative announced in the President's State of the Union Address – that we must change how we power our automobiles and that the Administration will increase research in batteries for hybrid and electric cars and in cars that run on hydrogen.

Mr. Dominique Portmann of DaimlerChrysler's hybrid vehicle program presented their 'alternative drive' propulsion strategy and lessons learned from Phase 1 of their plug-in hybrid van R&D activity. The strategy showed a transition from optimization of conventional internal combustion engines (gasoline- and diesel-fueled) to alternative liquid and gaseous fuels, followed by hybrid propulsion systems and ultimately fuel cell vehicles. The primary lesson learned from their Phase 1 plug-in hybrid program was the need for simplification – focus on core hybrid technologies (control, drive motor and battery) with all other parts carried over from their passenger hybrid car group and reduce to one vehicle type (i.e., configuration). Daimler plans for Phase 2 include two advanced prototypes for R&D and 18 additional test vehicles for the United States, targeting an electric range of 20 miles.

Dr. Mark Duvall of the Electric Power Research Institute presented his perspective as a representative of the utility industry. EPRI has studied plug-in hybrids for several years and their assessment of the technical challenges, energy and environmental impacts, vehicle certification issues and market potential was presented. The battery was identified as the key technical challenge, though Li-ion technology is considered promising based on preliminary testing. Their analyses show that grid electricity appears sufficient in the near term and typical wall plug outlets are preferred for recharging (i.e., customer and utility perspectives). Duvall said that plug-in hybrids are important for their near- and mid-term potential, but recommends that customer preference studies be revisited since vehicle attributes and the economic/political climate have changed substantially. He also stressed the importance of continued collaborative efforts.

Mr. Don Walkowicz, Executive Director of USCAR, noted several concerns with plug-in hybrid vehicles, including the lack of a common definition for plug-in hybrid vehicles and PHEV operating modes. In addition, substantial all-electric range in PHEVs will increase battery volume and mass (e.g. battery volume could be larger than a gasoline fuel tank for an EV range more than 10 miles). He also supported conducting vehicle and infrastructure analyses as soon as possible to quantify reductions in petroleum consumption and operating cost issues (but not focusing on CO_2 reduction). USCAR recommended that DOE develop a common set of assumptions and analyses for plug-in hybrids, assess and improve Li-ion battery technology for application to plug-in hybrids

and address the basic question regarding the appropriate role of government in offsetting increased cost to consumers (i.e., due to higher costs of technology required for the national environmental benefits).

Dr. Andy Frank, Director, Hybrid Electric Vehicle Center, UC Davis, presented an academic perspective. He was very optimistic and promoted producing PHEVs now – using today's technology – to reap immediate energy and societal benefits. His presentation reviewed the UC Davis vehicle experience and theorized a variety of uses for plug-in hybrids, ranging from private to fleet and military applications, stressing the increased independence from foreign oil and the synergy with renewable sources (hydro, wind and solar) due to the availability of "free" mobile energy storage.

Dr. Dan Santini from Argonne National Laboratory reviewed previous analytical studies regarding PHEVs that evaluated oil savings, greenhouse gas reductions, electric utility capacity, battery technology and customer needs. The studies showed that PHEVs could substantially lower petroleum consumption and emissions – though the results depend on PHEV market share and electric range. The studies also showed that market share will depend on the price and that consumers would benefit most if the electric range matched their daily driving pattern. Since the national average daily travel is about 30 miles, cost effectiveness analyses showed net benefits for PHEVs with 10- and 20-mile electric ranges and net costs for 40- and 60-mile ranges. Since batteries in today's hybrids are capable of only a few miles electric range, the studies recommended focusing battery development on the higher energy Li-ion technology that has shown promise in DOE and private sector developments. Santini challenged the attendees with a series of questions designed to test the validity of the assumptions/scenarios used in the studies.

With that technical background, the group facilitation process was explained and the participants were reassembled into their assigned breakout groups. Participants were asked by the professional facilitator in each group to openly discuss the key issues and make recommendations. Notes were taken, without individual attribution, as a basis for slides for the general session where the findings of the breakout sessions were presented.

Results from the Breakout Sessions

The following summaries are synthesized from the presentations prepared by each of the eight breakout groups, including their assessment of the key challenges, potential show stoppers, unknowns/data needs and recommendations/opportunities for DOE.

Vehicle Technology

Most agreed that cost is the primary impediment to producing PHEVs and batteries present the most significant technical challenge. PHEV prototypes have been built and demonstrated, but current battery technology is a potential show stopper for production:

- Specific energy is too low for an acceptable electric range. Batteries in today's hybrids provide only a few miles electric range, but longer electric ranges have been proposed for PHEVs.
- Battery life is expected to be too short for manufacturers to provide the same battery warranty as in today's hybrids due to more demanding deep-discharge cycles. Manufacturers presently provide up to 8 year/100,000 mile warrantees.
- Cost is too high – Larger/higher energy batteries than in today's hybrids cost several times that required for an acceptable incremental PHEV cost.
- Consumer safety of Li-ion batteries in vehicles needs to be demonstrated.

Higher power motors and power electronics (up to 2 times that of today's hybrids) are required for the same performance in hybrid and all-electric modes. Higher performance is achievable, but higher cost exacerbates the cost differential of PHEVs. The possibility of lower performance in electric mode was debated, but most agreed that full performance must be available on demand so safety is not compromised (e.g., crossing a busy street, freeway merging or passing). This could be achieved with instant-on engine capability, however the impact of sporadic starts on emissions must be quantified.

Potential Show Stoppers

- Battery specific energy, life and cost
- Motor and power electronics cost (for full performance in all-electric mode)

Unknowns/Data Needs

- Value proposition for the manufacturer/consumer – Production cost differential versus the value of PHEV features (e.g., electric range, emergency power, electricity cost versus gasoline savings).
- Impact of PHEV duty cycle on battery life – Today's hybrid vehicle batteries are used intermittently and typically discharged less than 5% before recharging. It is expected that life will decrease dramatically for a duty cycle that includes daily deep discharges of up to 90% and testing is strongly recommended.
- Standard analytical assumptions/data – The possibility of different performance in electric and hybrid modes as well as variation in recharge times (overnight and/or opportunity charging) directly impact the system design and could determine the economic/technical viability. Consequently participants stressed the need for standard definitions, driving cycles and recharge patterns, test procedures, etc.

Recommendations/Opportunities for DOE

- Continue to support R&D on advanced batteries, motors and power electronics
- Vehicle/component benchmarking – Using standard (TBD) PHEV test procedures
- Systems trade-off analyses using standard (TBD) PHEV daily driving cycles to determine configurations and control strategies that maximize PHEV benefits
- Comparative analysis of PHEVs versus high-efficiency, flex-fuel alternatives

Electric Distribution

The participants felt that there were no technical challenges for low-volume charging of PHEVs with today's infrastructure, though larger vehicles (i.e., bigger batteries) may have difficulty completely recharging during off-peak hours using a standard 115V/20A residential outlet.

Longer term, with a much larger vehicle population, smart metering and charge control at the utility level will likely be required to ensure off-peak charging, maximize overall system efficiency (vehicle plus grid) and minimize the impact of PHEVs on the need for capacity beyond current demand growth projections. The necessary technology is available to implement these features, but capital investment by the utilities is required for smart metering. Traditional off-peak pricing that does not require capital investment is also possible. The possibility of vehicle-to-grid (V2G) power delivery was discussed, but understanding the implications of large scale implementation requires further study. It was pointed out that grid interoperability is being addressed by DOE and the utilities for other applications.

Though the need for fast charging was debated, all agreed that it will present an additional technical challenge (near- or long-term). Participants pointed out that high rate opportunity charging for the convenience of the customer would be detrimental to the utilities and the environment, but industry representatives pointed out that time-of-day pricing would likely be structured to discourage the practice.

Though not a significant technical challenge, making safe and convenient public charge stations available for customers without dedicated parking/charging locations will present infrastructure implementation challenges.

Potential Show Stoppers

- None technical; possible exception – complications of mass on-peak charging
- High electricity costs (especially off-peak)
- Customers with limited or no access to charge outlets
- Restrictions on utility capital cost recovery

Unknowns/Data Needs

- Value proposition for utilities – Infrastructure cost differential versus the value of PHEV features (e.g., additional sales, V2G, emergency back-up service, etc.)
- Additional information on V2G needs, potential impacts, etc.
- Regional environmental impacts (CO_2, NOx, SOx, PM) due to shift from gasoline to electricity for a portion of the transportation energy demand

Recommendations/Opportunities for DOE

- Regional- and utility-specific cost-benefit and environmental analyses
- Interoperability codes and standards (including smart metering and control)
- Identification of unique technology development needs for PHEVs (grid interoperability, V2G-battery interactions, etc.)
- Consumer education

Customer Expectations

Though all agreed that behavioral studies (market analyses) are required to understand the motivations of mass market customers, most participants felt that PHEVs must compare to conventional vehicles in terms of convenience, performance, safety, durability and price. With the exception of early adopters, consumers are not expected to compromise – desiring choice and options as long as the incremental cost is acceptable.

Fuel economy must be superior to that of available vehicles (including hybrids) and it is more important than the electric range. Low cost, convenient recharging is expected – off-peak at home or anywhere an outlet is available. Smart cars and plugs will be needed – the customer will not likely plug in at a specified time (even for off-peak rates).

A key customer expectation expressed by the participants is that batteries will be expected to last the life of the vehicle or be covered under a reasonable warranty.

There was debate regarding the need for full performance in all-electric mode, but all agreed that safety cannot be compromised and full acceleration capability must be available when demanded (e.g., crossing a busy street, freeway merging or passing). Non-economic motivation (e.g., green image, national security) was debated, though it was unclear if it was well understood.

Potential Show Stoppers

- Cost was identified as the most significant issue for customers.
    - PHEVs will cost more to produce than non-plug-in hybrids (due to higher energy batteries and potentially higher power electric drives).
    - Most felt the PHEV cost differential using current technology would exceed the cost differential of the early production hybrids (estimated to be greater than $3000 compared to their conventional versions at that time).
    - According to some participants, the acceptable cost differential for today's hybrid vehicles is $650-1000.
    - As with conventional vehicles, it was felt that customers must be attracted with additional features (e.g., high fuel economy, emergency power back-up for the home) to justify a higher price.

Unknowns/Data Needs

- Value proposition for the customer – Incremental purchase price and operating cost versus the value of PHEV features (e.g., fuel economy, electric range, emergency power).

Recommendations/Opportunities for DOE

- A PHEV electric range requirement should not be specified – it is not justified by mainstream consumer demand, it drives costs up and reduces the likelihood of high volume sales to the mass market.
- Development, test and validation of PHEV research/demo vehicles
- Market analysis, customer education and learning demonstrations
- Increased public access to electric outlets for charging (e.g., apartment dwellers)

Government Role

The participants felt that the Federal government should be involved where societal and/or national strategic benefits are concerned.

- *Energy security* – the combination of plug-in hybrids and non-petroleum electricity generation could reduce dependence on foreign oil. Vehicle-to-grid power could reduce the severity of power outages (individually or regionally) or help prevent outages by improving grid stability.
- *Reduced emissions* – automotive and overall emissions can be reduced by using electricity from power plants that are cleaner than internal combustion engines.
- *Maintained mobility* – utilizing electricity for transportation diversifies the energy source and reduces the risk associated with disruptions in the oil supply.

Widespread implementation requires bridging multiple constituencies (e.g., energy, transportation, environmental) and cooperation among government regulatory agencies (e.g., the smart interface between the vehicle and the electric power grid, regulated investment cost recovery for the utilities).

Promoting national competitiveness was identified as a desirable role for the Federal government. In particular, the technical skills and technologies required for plug-in hybrids are also needed for fuel cell hybrids – a key component of the Administration's objective of achieving a hydrogen economy in the coming decades. The pre-competitive R&D required for plug-in/fuel cell hybrids is consistent with this objective and the goals of the FreedomCAR and Fuel Partnership.

Recommendations/Opportunities for DOE

- A recurring theme was the need for stronger bi-partisan support for a national energy strategy and a consistent message regarding the expected role of vehicles in that overall strategy (e.g., a higher government research budget to match the stated importance). The participants viewed PHEVs as one of a portfolio of solutions to achieve energy security and support was needed for several options.
- Vehicle development is the role of automotive manufacturers and government should set policy and support pre-competitive research for key technologies (e.g., batteries). The role of impartial broker was stressed – providing a repository for analysis and information, setting targets, establishing codes and standards, harmonizing regulations, facilitating interactions among stakeholders and providing unique research capabilities and facilities at the national laboratories.
- A comprehensive and objective system level assessment of national benefits of plug-in hybrids is required. The value proposition for manufacturers, energy suppliers, consumers and the nation should be quantified.
- Removing barriers to market entry, providing economic incentives (similar to current hybrid vehicles) and consumer education were identified by the groups as key government contributions to introducing plug-in hybrids in the market.

There was debate regarding the government role as researcher (technology development) and/or market driver (e.g., demo programs and incentives) and whether the R&D focus should be 'leap frog' or incremental technology improvement – there were proponents for both roles and focuses, but many did not see them as mutually exclusive.

Current Activities and Next Steps

Analytical studies are underway to identify technology development requirements for PHEV components and control systems. The DOE has also initiated development of procedures to evaluate PHEVs and has begun preparing R&D plans for PHEV technologies.

National laboratory capabilities and facilities are being assessed in terms of the key technical challenges and the opportunity to apply their resources in FY07:

- Modeling & simulation
- R&D for critical components (i.e., batteries, motors, power electronics)
- Component/subsystem testing and validation
- System and interface control development
- Vehicle testing and validation

Based on the enthusiastic participation of the attendees and the results of the meeting, it appears that further collaboration among government, academia and the private sector is warranted. DOE will identify additional opportunities for such collaboration and interaction.