Michael P. Walsh
Chairman, Independent Expert Panel
3105 North Dinwiddie Street
Arlington, VA 22207
July 27, 2007

Mr. Tom Cackette
Acting Executive Director
California Air Resources Board
1001 "I" Street
Sacramento, CA, 95812

Dear Tom,

Our Panel has reviewed the copy (to Fritz Kalhammer) of the letter Dr. Menahem Anderman sent you on June 22, 2007. Below is our point-by-point response to Dr. Anderman's critique, based on the best currently available information collected over the past year during our intensive research. In summary, nothing in Dr. Anderman's letter changes the conclusions we have reached in our study and Report.

The form of our response to the seven points made by Dr. Anderman is to summarize the Panel position, describe our rationale and then to present additional information items we feel are appropriate. If you have the time, you may wish to read the additional perspectives we offer on Dr. Anderman's points in the "Comments" paragraphs below.

1. *Panel estimate of energy capacity for PHEV batteries is too small.*

a) Panel position:

We disagree with Dr. Anderman's statement which is based on the contention that only about 60% of PHEV battery capacity (as opposed to the Panel's assumption of 80%) can be used if the required battery cycle life -- for example, about 2500 deep cycles over a ten year life – is to be achieved.

b) Rationale:

The Report documents cell-level cycling test results (Fig.3-2) that prove 2500+ cycle capability of SAFT's medium power/medium energy Li Ion technology at 80% depth of discharge (DoD).

It also shows a data plot (Fig. 3-3) from an ongoing test of the same technology at Southern California Edison (SCE) that by now has exceeded 2000 75% DoD cycles with only 5-7% declines of energy storage capacity and peak power. For a 20% loss (nominal end of life), these data extrapolate to at least 4000 and quite possible as many as 5000

75% DoD cycles. As noted in the Report, the SCE test uses multiple modules and a test cycle that simulates battery operation in a PHEV (see also Point 6 below).

The Report also notes that lives of 3000 and more cycles have been reported or claimed for several other Li Ion technologies [A123 Systems, Altair Nanotechnologies, and Kokam].

c) Comments:

Dr. Anderman contends that "essentially all experienced experts in the industry agree that the battery could not be cycled to more than about 60% of its energy", with the implication that battery capacities need to be 33% (factor 80:60) larger than those used in the Report. However, no hard evidence is offered by Dr. Anderman for this contention. Given the avowed lack of interest and activity in PHEVs and PHEV batteries by the major automobile and battery companies just a year ago, it seems doubtful to us that any of his sources have been conducting the several years of Li Ion battery tests simulating operation in a PHEV; they certainly did not claim to have done PHEV battery testing. Such tests would have been required to generate data of the type used under a) above to indicate Li Ion deep cycle life capability in PHEV applications.

The PHEV battery capacities used in the Report are not estimates of the Panel but are based on a study (M. Duvall et al., 2001, see Report References) conducted by a team of experts from GM, Ford, Volkswagen, EPRI, NREL, ANL and the University of California at Davis. In that study, the required battery capacities were derived from three quantities: the driving ranges of representative PHEVs on battery power alone, the fraction of battery capacity (taken as 80%) permitted to be used to deliver these ranges, and the representative per-mile DC energy consumption of battery-powered vehicles.

To provide a margin for the anticipated reduction of storage and power capacity over time, the Panel increased the minimum capacity needed for a PHEV-20 battery from 6 kWh to 7 kWh. Assuming 80% utilization of that capacity results in the availability of 0.8 x 7 = 5.6 kWh of DC energy from the battery. Note that a current, efficient electric vehicle with Li Ion batteries such as the AC Propulsion eBox (weight about 3000 lbs) uses well less than 0.25 kWh DC electricity per mile, or less than 5 kWh for 20 miles.

If for argument's sake one reduced the allowable battery capacity utilization to 75% (as employed e.g. in the SCE PHEV battery cycling tests), the PHE-20 battery assumed in the Report would deliver 5.25 kWh, still more than sufficient to cover 20 miles. Also, increases in electric drive vehicle efficiency are likely to be achieved as part of the ongoing substantial efforts to increase the "hydrogen mileage" of fuel cell vehicles. Although our Report does not make that assumption, the consequence of such efficiency improvements would be reductions rather than increases in the PHEV battery capacities from those used in the Panel Report for specified electric ranges.

2. *The Panel estimate for the cost of the PHEV batteries is too low.*

a) Panel position:

Dr. Anderman's assertion is given without basis or context. As clearly stated in the Report, our battery cost projections are based on projections/estimates given to the Panel by one NiMH and three different Li Ion battery developers/manufacturers. Their estimates were consistent with the bottom-up cost analysis performed by an independent expert in Li Ion cell cost estimation. Thus, we believe our cost projections for PHEV-size cells and batteries have a solid basis.

b) Rationale:

Most of the cost estimates acquired by the Panel from Li Ion battery manufacturers were for medium energy/medium power cells of around 40Ah and for complete batteries in the 15-25kWh capacity range, the cell sizes and battery capacities required for PHEV-40 cars and SUVs and for small BEVs. We obtained cost projections for different production volumes from these manufacturers, and the fact that the slope of these "cost learning curves" (see Fig. 3-4) were quite similar lends support to our projections as well as to their extrapolation to very large production volumes.

c) Comments:

The Panel was not given cost projections for batteries with the cell and energy capacities appropriate for shorter-range PHEVs and for HEVs on the one hand, and for full size, full performance BEVs on the other hand. As explained in the Report, we developed a cost model to project the battery costs for these other applications.

To increase confidence in battery cost projections, a series of materials, engineering design and manufacturing cost studies is needed, as mentioned in the Report. To the best of the Panel's knowledge, no such studies have been published, nor did the major battery and automobile manufacturers provide us with cost projections for PHEV-design and -capacity batteries that would support Dr. Anderman's assertion.

3. *The Panel estimate for the cost of existing HEV batteries is too high*

a) Panel position:

The Panel's cost projection for a 2 kWh battery NiMH HEV battery produced in large volume is about $2,100 (see battery cost for 2500MWh annual production rate, Table 3-14). This is quite close to Dr. Anderman's number for such a battery: "….leading to pack prices between $1000 [for a 1 kWh battery] and $2000 for the existing …. 2 kWh batteries".

b) Rationale:

The Panel's projected costs (prices to OEMs) for 2kWh NiMH HEV batteries are approximately $3000 at the 100,000 packs/year production level, and approximately $2,100 at the 1.25 million packs/year (2500MWh/year) production level, see Report Table 3-14. Since NiMH batteries are now being produced at the 500,000+ packs/year level by PEVE, $2,100 is the Panel's battery pack cost projection most relevant for comparison with Dr. Anderman's number for "existing [mass produced] batteries".

c) Comments:

The agreement between the Panel's projection and Dr. Anderman's information is gratifying, considering that the Panel's projections for NiMH HEV battery costs are based on extrapolations of PHEV-type battery costs to much smaller cell and battery capacities, and assuming that Dr. Anderman's information comes from major HEV battery and/or automobile producers.

The Panel's Li Ion HEV battery cost projections (Table 3-13) are lower than for NiMH at large production volumes, but since there are no commercial plants as yet for large-scale production of Li Ion HEV batteries, there is no real basis for comparison of the Panel's projections with a commercial product.

4. *The Panel assertion that the cost differential between a PHEV and HEV [battery] is only $800 to $1200 is off.*

a) Panel position:

The Report statement in question -- "Significant for the life cycle economics of PHEVs is that the incremental cost of a NiMH PHEV-10 battery over a full HEV battery is less than $800; for a PHEV-20 battery, the difference is about $1,200" -- is not an assertion as Dr. Anderman states but the result of the battery cost analyses and projections of the Panel that underlie the numbers in Table 3-14.

We disagree with Dr. Anderman's contention that a 5-6 kWh battery would be needed for a PHEV-10 vehicle (see 1. above). We also disagree with his statements: that a Camry 5-6 kWh PHEV battery would need to be "high power" and, more importantly, that the battery's per-kWh cost would be nearly the same as that of a HEV high power battery, see also Comments below.

b) Rationale:

Three important factors are reducing the cost difference between PHEV and HEV batteries well below what would be calculated if one assumed comparable per-kWh costs for these batteries : (1) optimized PHEV cells will be substantially larger (by factors 2 and 3.5 for PHEV-10 and PHEV-20, respectively) than HEV cells , and the cost per Ah (and thus per kWh) of PHEV cells therefore will be significantly lower than the per-kWh cost of small, very high power HEV cells, (2) important portions of the balance-of-plant costs (e.g. for the control system) are similar for PHEV and HEV batteries which means that the per-kWh costs of the BoP are significantly lower for PHEV batteries, and (3) for the same battery production rate (e.g., in packs/year), the battery capacity production rate (e.g., in MWh/year) is 2-3.5 times higher for PHEV batteries, so the per-kWh cost of PHEV battery materials will be lower in mass production.

These differences were evident in some of the battery manufacturer cost projections obtained by the Panel and they are quantified in the factors derived from that information (see Report Tables 3-11 and 3-12). Their cumulative impact is that the per-kWh cost of a mass produced 2 kWh NiMH battery is about $1000/kWh as compared to per-kWh costs of approximately $750 and $500 for complete PHEV-10 and PHEV-20 batteries, respectively.

c) Comments:

The Panel is not familiar with the Camry PHEV-10 study Dr. Anderman refers to (he does not provide a reference), so we are unable to compare and critique the assumptions and analysis methodology of that study with those underlying the Panel's results.
However, we stand on our results that a 4 kWh battery would be more than sufficient for a PHEV-10 car, and that in large scale production the per-kWh costs of NiMH (and Li Ion) PHEV batteries will be substantially lower than those for high power HEV batteries. Together, these results explain the relatively small difference in the projected costs of complete HEV and PHEV batteries.

Even if we assumed need for a 5-6 kWh [NiMH] PHEV battery for a PHEV-10 Camry, such a battery (energy density probably around 50Wh/kg) would be able to deliver the required peak power (about 60 kW, see Table 3-2) if it had a module-level power (weight) density of about 500-600 W/kg which was termed medium power in the Report. This is less than half of the 1200 W/kg typical for the high power density modules used in state of the art NiMH HEV batteries, with a consequent reduction of conductor and cooling system cost per kWh of PHEV cells and batteries.

In the Panel's cost model, a 5-6 kWh medium-power NiMH battery would cost approximately $3,300 - $3,500 in large-scale production (estimated by interpolating between the costs for 7 kWh and 4 kWh batteries shown in Table 3-14 for the 2500MWh/year production rate), and the cost difference between this and a high power HEV battery would be about $3,300 to $3,500 minus $2,100, or $1,200 to $1,400. This difference actually is overstated because it ignores the additional per-kWh cost reduction that can be expected for PHEV batteries if they were produced at the same rate (1.25 million packs/year) as the 2 kWh HEV battery.

Our bottom line is that in large scale production the cost differences between PHEV-10 and PHEV-20 batteries on one hand, and a HEV battery on the other hand will be modest, well less than the values of the incremental lifetime fuel cost savings enabled by the PHEVs vs. the HEV, see also below.

5. *The payback for [the battery of] a PHEV-10 Camry would be 18 years.*

a) Panel Position:

We agree with Dr. Anderman that, for his assumptions of PHEV-10 battery capacity and [NiMH] battery specific cost, payback would be that long. However, we disagree with his assumptions. Instead, we stand on our PHEV battery capacity and specific cost numbers that, together with the fuel cost and efficiency assumptions clearly stated in Appendix 16 of the Report, indicate much shorter payback times through fuel cost savings.

b) Rationale:

The discussion under Point 2 above summarizes the arguments for the PHEV battery capacities and specific costs discussed in the Panel Report in some detail, and it explains why and how we differ with Dr. Anderman's numbers.

c) Comments:

Regarding payback time, Appendix 16 of our Report does not include net present values (NPVs) of lifetime fuel cost savings for PHEV-10 vehicles. However, these can be interpolated from the NPVs for HEVs and PHEV-20s given in Appendix 16. For example, in the 10,000 miles/year, $3/gal and $0.06/kWh scenario, the fuel cost savings NPV for a PHEV-10 would be approximately $4,300 in 10 years. The comparison of this cost to the Panel's projection of about $3,000 for a 4 kWh PHEV-10 battery produced in large volume translates into a payback time of about 7 years. In the 14,000 miles/year, $4.00 and $0.08/kWh scenario, the fuel savings NPV for the PHEV-10 increases to about $6,300 and the payback time reduces to less than 5 years.

Even if we were to assume Dr. Anderman's stated need for a 5-6 kWh PHEV-10 battery (costing $3,300 to $3,500 in the Panel's model, see 4. above), the battery payback times for the two scenarios are about 8 and 5.5 years, respectively, far less than the 18 years claimed by Dr. Anderman.

Note that in the NPV/payoff considerations above we have not referred to the scenario (see Appendix 16) that is most favorable to PHEVs. In that scenario ($4/gal gasoline price; improved ICE and electric drive efficiencies) -- which seems very likely in the mid- and longer term -- PHEV battery payback times would be shorter yet by several years.

6. *The Panel assertion that there is data that suggests Li Ion batteries can meet the cycle life requirements of PHEVs is misleading since it is calendar life at high state of charge, particularly above room temperature, that is most eroding to Li Ion battery life. The data that the Panel refers to from Southern California Edison avoided that condition and is*

thus of limited relevance and should not be extrapolated to project life in an operating vehicle.

a) Panel position:

As noted in the Report we agree with the generally accepted view, also voiced by Dr. Anderman, that extended periods at high state of charge and elevated temperature reduce Li Ion cell and battery life. However, we disagree with Dr. Anderman's contention that the SCE test "…avoided that condition [of high state of charge and elevated temperature] and thus is of limited relevance". As stated clearly in the report, the SCE test simulates cycling of battery modules in actual PHEV operation, including representative periods at high state of charge and realistic battery temperature conditions. We believe that the SCE test results are not at all misleading but, on the contrary, represent a realistic test of Li Ion battery life capability in PHEV operation.

b) Rationale:

The SCE test of Li Ion PHEV batteries involves charging of multi-module units to full capacity at representative rates, discharging them in a simulated combination urban/suburban driving cycle to approximately 25% state of charge, operating the multi-modules at this rather low SoC in the charge-sustaining (HEV) mode, resting them for a period, and recharging to full capacity. This cycle is run continuously, resulting in performance of three to four cycles per 24 hours.

Therefore, with respect to the critical time at high state of charge, the SCE test subjects the test modules to a daily period at high state of charge about 3 times longer than they would be in actual PHEV operation which would involve only one discharge from 100% to 25% SoC and recharge to 100%. Thus, in this regard the SCE test simulates actual PHEV operation for 6 years, with the remarkable result that well over 90% of the original storage and power capacities are still available.

Regarding temperature, the test modules are kept at an external 25°C and during the test cycles internal temperatures never exceed 30°C. Because the SCE test simulates actual PHEV operation, module temperature conditions are expected to be similar to actual PHEV battery operation, including battery cooling. The importance of appropriate state of charge and temperature controls for achievement of long battery life is stressed in several sections of the Report.

c) Comments

The SCE test does not test calendar life for module operation at low(er) state of charge for more than two years. However, SAFT test data available to the Panel indicate very long calendar life capability for the type of Li Ion technology being tested at SCE. For example, at 100% SoC and 40°C, SAFT cells lost less than 4% capacity in more than 4 years, extrapolating to a calendar life in excess of 15 years under SoC and temperature conditions much more severe than those used in the SCE test.

Similar calendar life performance results have been reported by the same Li Ion battery manufacturers that claim achievement of more than 3000 deep cycles.

Finally, we point to the fact that Li Ion cells and batteries typically do not fail abruptly but lose storage capacity and peak power capability only gradually. One important consequence is that even after the nominal end of life (20% loss of capacity and/or peak power) batteries will continue to function near the levels, to which the vehicle user is accustomed, extending battery life even further in practice.

7. *The Panel assertion that [the] PHEV offers no consumer compromise is flatly wrong. Cargo volume is a significant consumer attribute and PHEV batteries, if installed in an existing platform, will occupy much of the cargo space. In fact the few companies with field experience with strong HEVs (Toyota, Honda, and Ford, PEVE, and Sanyo) unanimously agree that fitting in an existing sedan a battery that will support even a 10 mile PHEV is very challenging. For over 10 miles it is impractical.*

a) Panel Position:

We agree with Dr. Anderman that simply replacing a HEV battery with a PHEV battery in an existing HEV will reduce cargo volume, and this can be considered a customer compromise. Whether or not this is a significant compromise can be debated, especially considering the Panel's charter to project the characteristics and costs of ZEV technologies for the mid- and longer-term when these technologies are on public roads in numbers sufficient to impact environmental and energy issues.

The Panel's opinion is that early PHEVs will likely be HEV conversions, have rather short range on battery energy ("AER", for example 10 miles), and represent acceptable cargo volume compromises to their owners/users. As PHEV (including battery) technology evolves and market penetration increases, vehicle design modifications and purpose-designed vehicles are likely to emerge, driven by the financial, logistic and social benefits of deriving increasing fractions of vehicle propulsion energy from electricity. Together with gains in vehicle space and fuel efficiencies, these modified and/or new vehicle configurations will likely permit on-board battery capacities sufficient for AERs of 40 or more miles.

b) Rationale:

Early PHEVs will likely be low volume HEV conversions, and the cargo volume compromise will be mitigated in the minds of the early adopters by the benefits associated with plugging-in to the grid. In a historic example, the first cars with air conditioning systems had significant cargo volume compromises yet early adopters still bought them for the attributes they provided. Today air conditioning is virtually standard on U.S. vehicles and no one considers it a packaging compromise. We also note that the first-generation Toyota Prius represented a significant compromise in performance, a very important expectation of most automobile buyers. Yet, the new vehicle concept sold sufficient vehicles to buy the time needed by manufacturers to improve battery and vehicle technology performance.

For the mid- and longer term, existing vehicle platforms appear to offer sufficient space to accommodate compact-design Li Ion batteries of at least 10 kWh and perhaps as much as 20 kWh, sufficient for efficient PHEV-25 to PHEV-50 vehicles. For example, the 9-10 kWh battery of the Energy CS Prius PHEV conversion delivers up to 30 miles AER yet fits into the vehicle with little loss of trunk space. The Dassault (France) PHEV conversion of a small Renault Kangoo pickup truck accommodates a 20+kWh battery with almost no loss of cargo space. Vehicle designs such as the Daimler A Class and B Class, unquestioned commercial successes in Europe, would offer sufficient space for such batteries (or fuel cells).

Finally, the Panel believes that General Motors would not invest in developing the Saturn Vue PHEV or the purpose-designed PHEV-40 Volt if the company did not believe these vehicles will have competitive cargo space.

c) <u>Comments:</u>

The package compromise issue with conversions of existing vehicles has been brought up in the past, especially by those who wanted to list reasons why PHEVs are "not feasible", seemingly ignoring the fact that over time vehicle architectures continuously evolve to accommodate the product content that customers want to buy. For example, recent PHEV concept vehicles using unique architectures such as the Chevrolet Volt and Ford Edge HySeries do not appear to have package compromises. Moreover, based on published interviews with their executives, General Motors seems to be relearning from the sales success of the Toyota Prius HEV that (in addition to solving packaging issues) a unique vehicle architecture can provide significant marketing advantages for an alternative technology and fuel vehicle. The associated instant recognition and status for the owner/driver can lead to successful sales of the product and important image benefits for the manufacturer.

<u>**Summary**</u>

In summary, the Panel's independent expertise was brought to bear on the issues we were asked to address and was informed by the numerous discussions and exchanges we had with leading organizations and their experts around the world. As part of that effort, we observed that battery and vehicle science and the technology have moved forward in the past several years, and that substantial further gains are likely in the mid and longer term. One consequence is that the relative merits of PHEVs and Li ion batteries compared to HEVs and NiMH batteries, respectively, are shifting significantly as documented in the Panel's report. The recent announcement of Toyota's plans to test a prototype PHEV on public roads in Japan can be taken as evidence of this development. Therefore I urge you and the Board to not be distracted by Dr. Anderman's comments on selected sections in the Report.

As Panel members we hope these comments are helpful. Please don't hesitate to contact me if you, your staff and/or the Board desire additional clarification.

Best regards,

Michael P. Walsh,
Chairman, Independent Expert Panel