ADVANCED AUTOMOTIVE BATTERIES

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Feedback on ARB's Zero-Emission Vehicle Staff Technical Report of 11/25/2009 including attachment A: Status of EV Technology Commercialization

General

Thank you for the opportunity to provide feedback on your recent staff report. The overall report is an excellent document that provides a realistic assessment of a very complex subject. I am in general agreement with the theme of the report, its assessment of the progress in the relevant technologies, and the comments regarding the challenges and risks ahead.

As part of a current multiclient study of the outlook for EVs and PHEVs, I have recently had the opportunity of visiting the battery technology groups of nearly all the major carmakers and foremost advanced automotive battery developers in the six countries with the largest automotive industries. It is clear that the level of effort in PHEV and EV battery development has greatly increased over the past three years. However, according to most of the companies I visited the commercial viability of these technologies for the mass market is still highly questionable, and that of FC vehicles is even further on in the future.

Virtually all the current development programs involve Li-Ion batteries. Due to their higher energy density and correspondingly lower volume and weight per unit of energy, Li-Ion batteries simplify vehicle design. Yet most EV development programs in major car companies are focused on subcompact to compact cars with batteries of 15 to 35kWh and real-life driving ranges of 70 to 125 miles (generally similar to the NiMH-powered vehicles developed under the MOA with CARB during 1998-2001). Thus, the lighter weight of Li-Ion batteries is not being translated into longer driving ranges. There are several reasons for this, the most important being high battery cost. Carmakers reckon that vehicles with larger capacity batteries (40 kWh and up) would be too expensive for market acceptance.

EV Battery Technology

My visits confirmed the industry consensus that the challenges to the mass commercialization of EVs & PHEVs are largely related to battery technology. They include:

1. Safety

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Significant improvements in Li-Ion battery safety have been achieved following the major safety-related recalls of Li-Ion batteries for computers and other applications in 2006. Yet the safety of most Li-Ion batteries for EVs is far from proven. Some safety enhancements come with a higher manufacturing cost, some with a sacrifice in performance and many through improvements prompted by the experience gained during the early stages of pack integration and field trials. Safety is of course the most critical parameter and trumps any plan to reduce cost or improve performance.

2. Reliability / Manufacturability

After safety, reliability is the next most important criterion. Battery reliability in the field is critical and most experienced battery manufacturers are careful to take the time to optimize cell and pack engineering, and to develop manufacturing equipment and processes that can support the high-throughput, high-yield production of a reliable product. The industry must learn from the past experience of those NiMH automotive battery developers who had projected low pricing and high performance but failed to establish reliable manufacturing processes, and essentially dropped out of the market. Manufacturing is generally more demanding for Li-Ion batteries than for NiMH batteries and to meet the high-voltage, high-energy, high-power, and long-life requirements, the importance of proper cell, pack, and manufacturing engineering cannot be overemphasized.

3. Durability

There have been significant improvements in Li-Ion battery cycle and calendar life capabilities since the CARB 2000 panel report and our update in 2003. The technology seems adequate for EV applications, at least in relation to cycle life, with over 2000 cycles at 70—80% DOD demonstrated by several developers. However, the more difficult area to control is calendar life since Li-Ion batteries degrade as function of state of charge (SOC), temperature, and time. Battery life is affected by cell chemistry, pack design, cooling method (if any), and vehicle duty-cycle. It is important to note that some of today's most publicized EV efforts involve batteries with no active cooling and whose life expectancy in warm weather is likely to be far shorter than the 10-year CARB emission-control warranty. Here again the most experienced long-term players in the industry stress that they prefer to prioritize battery life even if it is at the expense of cost and performance. Please recognize that economic analyses of EVs based on a 10-year battery life will simply shatter if the actual battery life in the field does not meet this expectation, and two or more batteries are required over the useful life of the car.

4. Cost

In our current multiclient study we put considerable effort into analyzing battery cost based on: i) ab initio cost models utilizing realistic cell and pack designs and quotations for materials from several key materials suppliers, and ii) several actual cost estimates given by major battery makers to major car makers. When we apply our base estimates to the volumes studied by the CARB 2007 Technology Panel, we obtain considerably

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higher battery cost estimates for EVs, namely $500 to $700/kWh in 2015, for the 500-MWh case (a plant producing 20,000 packs averaging 25kWH each annually), and $375 to $500 per kWh for a plant producing 2,500MWh (100,000 25kWh packs annually) for the 2018-2020 timescale.

We focused our study on data from the major materials, cell, and pack producers and avoided projections from less experienced companies. This may explain the higher pricing in comparison with the CARB Panel study. Also, we and our information sources priced in what we believed will be necessary to meet the most important criteria for commercialization, namely safety, reliability, manufacturability, and durability. (In this connection we suggest avoiding the use of Tesla data as criteria for battery cost. Tesla uses computer cells that have a life expectancy on the order of 2 to 4 years, and there are no data in the public domain to project their durability and reliability in a vehicle battery. Tesla may have a business motivation other than profitability to sell an aftermarket battery option with the original vehicle.)

The cost of PHEV batteries per nominal kWh, depending on duty cycle, is expected to be 20% to 30% higher than that of EV batteries. However, since their usable capacity is likely to remain between 55% and 70% of nominal, as opposed to 80% to 90% for EV batteries, their effective cost is about 60% to 100% higher.

5. Performance

Modern EV Li-Ion battery cells deliver 100 – 140 Wh/kg and 200 – 275 Wh/liter with good power. These numbers show a greater spread for battery packs as they are affected by the weight and volume of the cooling scheme, if any. It is worth recalling that the best cylindrical consumer cells deliver 220 Wh/kg and 600 Wh/liter. The gap in performance between the best consumer cylindrical cells and current EV cells is related to the compromises made in the design of EV cells to support the four key requirements of safety, reliability, durability, and cost. EV cell and battery performance can possibly be increased with the four key parameters still being satisfied, but this will take several years to confirm. In the case of PHEV batteries, the most important objective will be to increase their usable capacity and thus their effective energy density, thereby reducing their cost.

Technological breakthroughs with a positive impact on performance are always possible but cannot be predicted, nor can policies be based upon them. Furthermore, significant improvements in performance (from, say, high-voltage cathodes or silicon anodes) will only be beneficial if they do not reduce the battery's ability to meet the four important key requirements. We nevertheless remain hopeful that the recent major international public and private investments in battery technology will, in the long run, yield batteries with higher performance.

Advanced Vehicle Status and Policy Recommendations

At fuel pricing below $4 per gallon in the US, the total cost of owning and operating advanced vehicles will clearly exceed that of conventional vehicles. With gasoline at

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about $4-5 per gallon, hybrid-electric vehicles become cost competitive. PHEV vehicles will only become cost-competitive when the price of gasoline exceeds $7 per gallon – even if we assume batteries with an 8-year life (which is far from being proven) and battery pricing below $500/kWh (late in the decade). Electric Vehicles will reach that point at similar or even higher gasoline price levels, depending on battery size (and thus vehicle range). These numbers include the assumption that Li-Ion PHEV and EV batteries will prove safe, reliable, and durable, and that price reduction efforts are successful. We do not have good estimates for FC vehicles but their economics in the next 20 years are likely to be even more problematic than that of PHEVs and EVs with a100-mile range.

It is generally accepted in the industry that the closer the technology is to the market, and the more experienced a particular company is in high-volume manufacturing and application of the product, the more conservative (or realistic) that company will be relative to future cost/performance ratios. Applying this maxim to advanced vehicle development (as described in the ARB staff report and the studies quoted therein), indicates that the cost and durability projections for fuel cells are probably the most speculative. The same projections for PHEV and EV batteries are of intermediate credibility, while for Li-Ion HEV batteries they are somewhat more reliable, and for NiMH HEV batteries, quite reliable. It is also important to remember that HEVs require no investment in infrastructure, PHEVs a limited investment (involving a greening of the grid), EVs a somewhat larger investment, and FCs a massive investment in hydrogen production and distribution.

Furthermore, during my visits it also became apparent that several (but not all) car companies had redeployed technical staff from fuel-cell development to work on Li-Ion batteries. In addition, some of these companies also mentioned that technology investment in the FC-component supply chain is in decline. These two changes combine to reduce the likelihood of the fast progress in fuel-cell technology that was expected a few years ago.

We maintain that it is very unlikely that either FC vehicles or battery electric vehicles could be competitive in the mass market before 2020, or probably even 2025. To reduce CO_2 emissions from vehicles, starting in 2015, it is clear that CARB will have to promulgate and enforce some severe restrictions, and increase them annually to meet the desired goal. Providing limited incentives for early demonstrations of advanced technologies (PHEV, EV and FC vehicles) could complement its policy but should not constitute its basis, so as to allow the policy to remain technology-neutral.

We propose that CO_2-emission regulations should also be accompanied by an increase in fuel cost via a fuel tax or other mechanism. This may very well be the most effective way to accelerate the introduction of transportation with near-zero carbon footprint by affecting the demand for fossil fuel. Although drivers may have to pay more for a gallon of gasoline, with good education that can be sold to the public and their use of more fuel-efficient vehicles will minimize the cost impact. Furthermore, a reduction in fuel consumption may alter the supply/demand equation sufficiently to delay future oil-price escalation. Eventually, a win-win situation could develop with the consumer benefitting

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from a lower overall fuel bill, the environment from lower CO_2 emissions, and governments from increased revenue—all in support of the energy supply and environmental causes.

The ARB staff's assessment that a notable impact on the environment will lag behind new product introduction by 20 to 30 years is correct. It is the main reason to promote the expanded use of HEVs. This technology is road-proven and already delivers an approximately 40% reduction in CO_2 emissions, and even more in pollutant emissions. A 50% market share for strong hybrids in California by 2020 is feasible and would thus reduce CO_2 emissions from new cars by about 20%. In contrast, given the problems in using the existing electrical grid, the environmental benefits of PHEVs in comparison with HEVs are relatively small. When this is compounded with the more difficult commercial threshold for mass production of PHEVs, the likelihood that these vehicles can make a notable impact on the environment within the next 20 years is slim.

RECOMMENDATIONS

Based on our understanding of the technical and commercial barriers to the introduction of advanced vehicle, we recommend the following guidelines for future policies:

1. CARB to increase the requirements for new-vehicle fuel efficiency by about 4% per year, starting at the earliest feasible date and continuing indefinitely,

2. CARB to initiate a drive to increase gasoline taxes nationally, in collaboration with interested political and environmental lobbying groups,

3. CARB to enact policies to accelerate the "greening" of California's electrical transmission grids, and

4. CARB to provide some incentives for the early introduction of EVs and FC vehicles provided they are matched with measurable progress in drastically reducing the carbon footprint of the energy source (electricity or hydrogen).

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