HOW AUTOMOTIVE BATTERY DEVELOPMENTS WILL INFLUENCE FUTURE STATIONARY BATTERIES

Daniel C. Cox
Technical Support Manager
Midtronics, Inc.
Willowbrook, IL 60527 USA

ABSTRACT

Stationary battery installations have a number of performance requirements that are well documented. Discharge capacity ratings and the environmental operating profiles are all spelled out in the manufacturers' brochures. Lead/Acid battery construction has been an industry staple for years, based on cost, performance, availability and relative safety. This may continue to be the case for the immediate future, but new developments in automotive battery applications may have a dramatic impact on the stationary battery world as new developments occur. This paper will attempt to summarize and provide some insight into what kind of battery developments are being done for Hybrid and some pure electric vehicles and how that research will likely impact stationary battery installations in the coming years.

To suggest the automotive industry is struggling in 2009 may be a bit understated. Although demand for new vehicles remains strong, the demand in large part is focused on vehicles that are capable of more fuel efficient operation. The need for greater efficiency was highlighted through the summer of 2008 by the global spike in oil prices. Automotive Hybrid drive systems combine an Internal Combustion Engine (ICE) and some type of battery and do offer some promise for overall improved operating economy. The ideal battery to combine with the ICE will be a chemistry that is safe and lighter than any current lead based construction. The design must also be capable of delivering perhaps a quarter million discharge cycles to 80% Depth of Discharge, with a minimum service life expectancy of 10 years. Future batteries will also be required to operate across a huge temperature range and do it at a competitive cost when compared with current product options.

A BRIEF HISTORY

Between 1832 and 1839 (the exact year is unknown), Robert Anderson of Scotland invented the first crude electric carriage. A small-scale electric car was also designed by Professor Sibrandus Stratingh of Groningen, Holland and built by his assistant Christopher Becker in 1835. Practical and more successful electric road vehicles were invented by both American Thomas Davenport and Scotsman Robert Davidson beginning around 1842. Both inventors were the first to use non-rechargeable electric cells. Frenchmen Gaston Planté invented a better rechargeable storage battery for electric vehicle use in 1865, and his fellow countryman Camille Faure improved the storage battery in 1881. This improved-capacity storage battery paved the way for electric vehicles to flourish. This shows there has been a history of development on electric vehicle batteries long before the most recent flurry of activity. It also shows that electric drive vehicles significantly predate what we now know as the automobile industry.

But why is there a need for Hybrid cars, and why now? If you haven't heard the news, the world will run out of oil! Our modern transportation systems and many of the things we do daily are possible only because of the availability of fossil fuels, and that means oil. When will the headline in the Wall Street Journal read "Saudi Arabia Runs Dry!" Of course, this is referring primarily to "cheap" oil, and it does not include other sources of energy we currently rely upon. The United States has significant coal and natural gas reserves, plus hydroelectric power generation is critical for heating and lighting needs in our cities and towns. Add to that the nuclear generation capacity, along with the newer "greener" sources for renewable energy like wind, solar, and geothermal. Each source will have its place in the future as technologies to produce them emerge, but there is one small problem – they all generate AC energy that can't be stored. This suggests we will need significant new battery storage capacity to take full advantage of our available energy resources.

BATTERIES FOR FUTURE ECONOMIES

The battery is a limited resource in any power equation. In vehicle applications, this is commonly reported as Watt Hours per Kilogram (Wh/kg), relating to specific energy content compared to physical weight. For now, the majority of batteries used today in production Hybrid vehicles are Nickel Metal Hydride (NiMH) construction because of their relative performance characteristics. But Lithium Ion batteries (Li-Ion) are considered the front runner for future development, based on their energy density, lower weight, relatively small physical volume, and excellent cycling capability. Safety issues are the primary challenges for the suppliers interested in delivering lithium cells in large volume for vehicle use.

One of the most dramatic differences comes in when you start to evaluate deliverable energy sources for vehicle applications. There is no contest here: Gasoline ~12,200 Wh/kg; Li-Ion Batteries ~150-200 Wh/kg. It is easy to see why battery performance will continue to be a major challenge for motive power applications in the years to come. The distribution network for gasoline and diesel is already in place and well established – a power grid with the generation and distribution capacity sufficient to replace an equivalent in energy for vehicle transportation are a distant reality. Thankfully for stationary battery installations, physical volume and weight factors are much less of a consideration in contrast to cars and trucks, but safety and float life are still paramount. Current statistics for the power grid in the US show we have AC mains power available over 99% of the time on average. With lead/acid batteries dominating most stationary installations, changes in stationary battery product requirements can be expected to emerge slowly. However, the battery development work being done in the automotive Hybrid and EV marketplace are expected to eventually play a role in how we heat and light our cities and homes, along with powering our cars, busses and trucks in years to come.

HOW HYBRID-ELECTRIC VEHICLES WILL PLAY A ROLE.

The term “Hybrid vehicle” describes “any car, truck, bus, train or other vehicle system where two or more sources of energy are used for propulsion.” Hybrids vehicle combine a conventional Internal Combustion Engine (ICE), either gasoline or diesel, with some battery or other temporary storage medium used in combination. The most basic designs are 12 volt AGM lead/acid battery systems now being used in a Start/Stop application, primarily in Europe. More powerful and complex versions operate at up to 360 volts, with Lithium Ion battery packs, and have the option to plug into the grid to maintain battery charge. These plug-in Hybrid cars are scheduled for release in vehicles like the Chevy Volt or the Fisker Karma, both scheduled for release in early 2010. The basic 12 volt Idle-Stop versions offer some modest fuel savings, but as the complexity increases, so do the fuel savings, with a more sophisticated and more expensive integrated drive system allowing pure electric operation for as much as 40 miles. Keep in mind, none of these Hybrid vehicles are “pure electrics,” but all have some form of stored energy and the ICE combination. Reduced fuel consumption is the most compelling reason for the research and progress being made into more efficient energy storage options – because high performance batteries must be included for these vehicles to ever be successful on a large scale.

Along with the prevailing market presence of simple Hybrid cars and trucks, there are two more design options showing some signs for future potential. There are some “plug-in Hybrids” either planned for production or being offered as modification “kits” for existing Hybrid production cars. This should give an increased driving range on pure electric power, over what the ICE/Battery Hybrid design can provide. The plug-in Hybrid cars could be used as commuting vehicles and still have operating ranges of several hundred miles when combined with the ICE operation. Pure electric vehicles, which must be plugged in, are a rather rare exception to the rule today, primarily based on extremely high comparative cost and significantly shorter driving ranges. The new Chevy Volt will marry the two worlds together, with a small on-board ICE, a medium sized Li-Ion battery pack, and the ability to plug in for recharge also. This car is being advertised as having a 40 mile range as a pure electric operation.

REALITY CHECK TIME

There is a price to pay for more efficient vehicles. Along with that increased vehicle price is the realization of what the consumer really gets and what makes economic sense. In Figure 1, you can see the expected payback on your investment, predicated on making several assumptions. Note the graph shows over seven years will be needed to recoup the extra cost of a simple Hybrid, or six and a half years for a Plug-in Hybrid car using the reference formulas.

This is not the kind of economic puzzle most consumers are willing to buy into – yet! Like with any formula, as the values change, the equation can shift rather dramatically also. The table shown below is from the American Council for an Energy-Efficient Economy (**ACEEE**) at **http://www.greenercars.org,** which points out the relative economic impact of buying a car with a cost premium of roughly $4,000 dollars. By using fuel savings alone, a simple Hybrid car will take you more than seven years to reach a breakeven point. Of course, you will have the satisfaction of knowing you acted responsibly, but are you prepared to make the investment? How confident are you that fuel prices will remain relatively low? At the time of this writing, gasoline in the Midwest is hovering around $2.00 per gallon. The equation gets a bit simpler if gasoline goes to $6.00 dollars per gallon or more, which makes it similar to European prices, and the time may be near. Changes are coming, perhaps even faster than we are comfortable with.

Plug-In Hybrid Payback - ACEEE

Table 8, Plug-In Hybrids, ACEEE, Sep 2006			Calculated
	Hybrid	**Plug-In, 40-Mile range**	**Plug-In vs. Hybrid**
Near-term Incremental costs			
Battery - $/kWh	$2,000	$1,500	
Battery – total cost	$2,000	$17,500	$15,500
Other incremental costs	$1,500	$1,500	0
Annual fuel savings	$480	$705	$225
Payback (years)	7.3	27.0	68.9
Long-term Incremental costs			
Battery - $/kWh	$400	$295	
Battery – total cost	$600	$3,500	$2,900
Other incremental costs	$1,000	$1,000	
Annual fuel savings	$480	$705	$225
Payback (years)	2.9	6.4	12.9

Assumptions – 12,000 miles per year, hybrid FE of 50 mpg, conventional vehicle FE of 30 mpg, 50% of plug-in miles on electricity, $3.00/gal, 4.0 miles per kWh, $0.09/kWh, no discount of fuel savings, **no additional cost for motor and power electronics, no FE penalty for additional weight of plug-in batteries, no battery replacement for plug-in**

Figure 1: Reality from the American Conference for an Energy-Efficient Economy (ACEEE)

Reducing our total energy consumption will only be possible if there is a fundamental shift in the energy consumption patterns of all major consumers – the US in particular. To put things in perspective, according to 2007 statistics, the world is consuming 85,085,664 barrels of oil on average daily (www.NationMaster.com global statistical summary of global oil consumption). The United States leads all other countries using >20.1 million barrels, with China currently coming in a distant second place at just under 7.6 million barrels and climbing. Part of the distinction is the result of the US having higher total production requiring additional resources. This does not represent total energy use, of course, but over half of those 20.1 million barrels goes directly into production of gasoline and diesel fuel. From communications to lighting, transportation, home heating, and just about everything else you can think of, they are all tied back to the consumption of energy. So what does this have to do with batteries? You may recall the experiment run by California Edison and EPRI in the late 1980's where they built a large battery storage facility to demonstrate how batteries could be used for supporting the power grid by load leveling or peak shaving during changes in demand during the course of the day. Although the project was only functional for a relatively short time, it did demonstrate the ability of batteries to contribute to improved power management on a large scale.

WHICH BATTERY CHEMISTRY WILL PROVIDE THE ANSWER?

Numerous engineering groups and battery manufacturers around the globe are working to come up with the most attractive battery design that will advance the state of the art. Groups from Japan, Korea, Australia, the US and all across Europe are seeking the battery characteristics that match the industry challenges. In general, the new batteries will need to be safe and able to be produced in huge quantities. The batteries must provide significant discharge cycle performance with better energy density when compared to traditional flooded lead/acid batteries. The batteries may need to deliver as many as 250,000 charge/discharge cycles at up to 80% Depth of Discharge (DoD) along with operating well at temperature extremes. They will need to have smaller physical displacement and, like everything else in the car business, they will need to be price competitive with traditional lead/acid batteries. No small task, it seems.

Something unique about virtually all Hybrids is that the high voltage battery packs are engineered and controlled to operate at something less than 100% State of Charge. Because these vehicles use regenerative braking, the energy captured during the braking action must go somewhere or it will simply be lost as heat through conventional hydraulic braking systems. Upon acceleration, the captured energy from the battery is then sent back through the motor/generator to give start assist or, in some cases, to propel the vehicle as a pure electric for some distance. Every time you press on either the gas or brake, the battery SoC will be changing. The situation may be a bit different for a plug-in Hybrid, based on the supplemental charge energy made available off the power grid. In those cases, the high voltage battery SoC equation is likely to be shifted a bit higher by design to allow an improved operating range as a pure electric vehicle.

No battery is perfect. Work being performed by Argonne National Laboratories was reported on last September at the facility's First International Conference on Advanced Lithium Batteries for Automobile Applications, and it is referenced in Figure 2. This graph clearly shows that the NiMH batteries used in strong hybrids have shown some substantial capacity loss or aging effects.

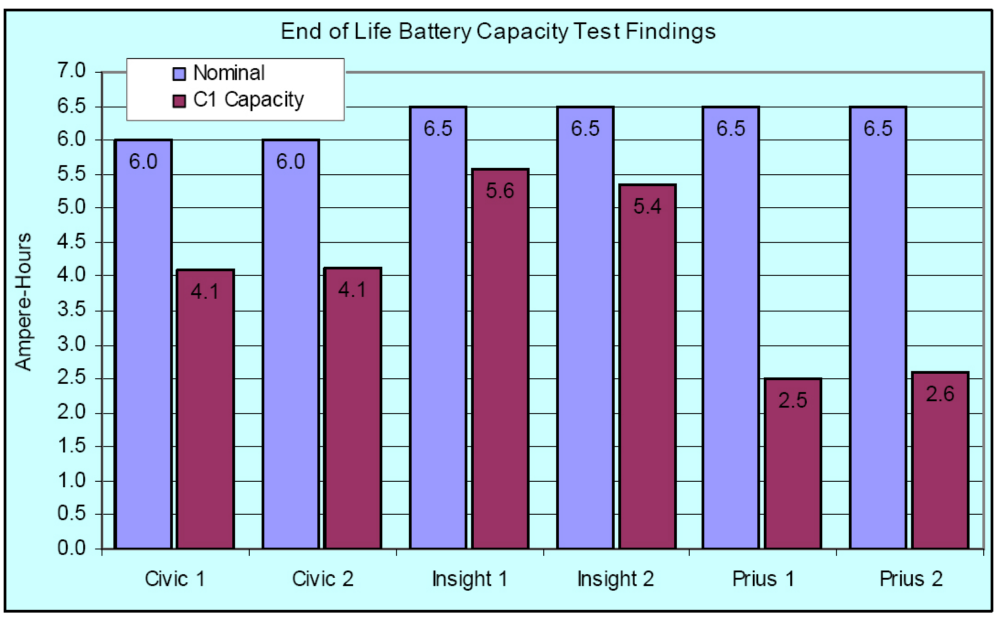

Figure 2: Capacity loss in NiMH batteries

In Figure 2, the C1 value represents the rated cell capacities compared to the actual cell capacities after ~100,000 miles of vehicle operation. These examples after cycling range in actual performance from a low of 39% to a high of 86% when compared to their rated capacities. Studies are underway with many familiar materials, ranging from Alkaline, Carbon, Lithium, Manganese, Mercury, Ni-CD and Ni-MH and, of course, lead. Two new variations on the lead/acid battery were recently reported on in the December 2008 IEEE Spectrum magazine that are actually being called "Hybrid Batteries." These battery designs are combining traditional lead-acid construction with ultra-capacitor components into what are being called "ultra batteries." A company called Axion has developed a proprietary PbC battery technology which is multicelled supercapacitive, with a lead-acid-carbon electrode hybrid design. They have replaced the traditional lead based negative electrode with an activated carbon electrode to improve cycling performance and deliver longer service life with lower weight along with much faster charge and discharge performance. FireFly Energy from Peoria, IL is also working with carbon-foam negative to achieve similar performance advantages over traditional lead/acid cells. These types of advances should provide a lower cost option than the nickel based batteries, and they already have proven safety aspects when compared to any of the current lithium options being offered for motive power use.

There has also been an announcement of a joint venture between Furukowa Battery, Yokohama, Japan and East Penn Manufacturing, Lyons, PA. These companies will be producing a new capacitor/battery combination they are calling an "Ultra Battery" http://www.furukawadenchi.co.jp/english/rd/nt_ultra.htm . This is another design combining a capacitor with a lead-acid battery targeted for the next-generation automobile. This option is slated to be used in applications such as idling-stopping cars, mild Hybrids, and potentially with other instantaneous heavy load applications. All of these new combinations are reported to dramatically improve cycling capability and are able to be produced in large quantities while at a significant cost savings when compared to the NiMH products now used in Hybrid cars. Of course, the marketplace will ultimately determine which of these or other products will be successful in a very competitive automotive marketplace. But the battle is on and the stakes are high for any supplier that can match the needed performance and do it at a reasonable price.

SUMMARY

There is no question that the efforts being applied by a multitude of battery manufacturers and research groups will develop batteries that will meet the evolving demands of modern vehicles. No matter what the application might be, if performance or cost benefits are identified when researching these automotive battery programs, it is logical that those benefits will ultimately transfer into many other battery applications. As infrastructure investments are made for mining and producing new battery products, the supply side dynamics will certainly be affected. For stationary battery installation, a new round of performance evaluations and cost comparisons can be expected to follow in the not so distant future. Who will be ready for the challenge?