GAME CHANGER? THE POTENTIAL IMPACT OF VEHICLE ELECTRIFICATION ON THE STATIONARY BATTERY WORLD

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ABSTRACT

After about a hundred years of false starts, the electric vehicle (EV) is finally coming of age. Starting with the first Toyota Prius hybrid electric vehicle (HEV) and leading to plug-in hybrid electric vehicles (PHEVs) like the Chevy Volt and pure EVs like the Nissan Leaf, vehicles with some form of electric drive are finally taking off. Spurred on by targets of a million plug-in vehicles on US roads by 2015 and $2.4 billion in stimulus funding, the lithium-ion battery industry in the USA has built huge factories to meet EV demands.

What does all this mean for the stationary battery world? Fortunately, the market for grid-connected energy storage systems is emerging at about the same time that production capacity is increasing. However, if EV adoption proceeds at a slower pace than some have predicted, leading to overcapacity in battery production, could this lead to some manufacturers to promote Li-ion batteries aggressively in traditional standby applications? As described in recent Battcon papers, Li-ion batteries can provide significant benefits in some applications and potential pitfalls in others.

This paper provides a brief history of EVs and discusses the significance of Li-ion technologies in the final emergence of commercially viable vehicles. The position of Li-ion in the grid-connected energy storage market is assessed compared to that of other emerging battery technologies, and the likely spillover of these products into the standby market is discussed.

Will massive increases in Li-ion battery production lead to a scarcity of lithium? Will other lithium-based batteries, or other non-lithium energy storage devices, take over from Li-ion in the foreseeable future? Is this the beginning of the end for lead-acid and nickel-cadmium batteries? The paper will address such questions, but on some of these issues the debate is just beginning.

EV HISTORY

The first automobiles appeared with a variety of drive systems, including steam, gasoline, and electricity in the form of batteries. One of the leading battery companies in the field was the Electric Storage Battery (ESB) Company of Philadelphia, which held numerous patents on lead-acid technology and produced the Exide battery. Competing against ESB was Thomas Edison, who wanted to develop a lighter and more durable battery and eventually came up with the nickel-iron cell. As the nickel-iron product was steadily improved, Edison came up with one of the first recorded uses of lithium in batteries, where he found that the addition of lithium hydroxide to the electrolyte of his cells had a major effect in improving capacity and longevity.

Of course, such improvements couldn't keep up with the rapid advances in gasoline engines—and particularly the introduction of the electric starter motor—and electric vehicles went into their first period of dormancy. By the 1960s and 70s, however, choking smog and oil embargoes led to a brief revival of the EV concept, with various car companies experimenting with radically new electrochemical couples, including Ford's work with sodium-sulfur technology and GM's efforts with nickel-zinc.

Eventually, though, oil prices fell back to low levels, as shown in Figure 2, and all this work faded away. By 1996 what the market was left with was the General Motors EV1. Produced in response to the California Air Resources Board mandate for 'zero-emission vehicles,' the EV1 was not available for sale but was leased to the public in selected markets. Although there was a much-publicized option for a nickel-metal hydride battery, the vast majority of EV1s were powered by lead-acid batteries. The EV1 was produced until 1999, and in 2002 GM repossessed the entire fleet and crushed or shredded most of the vehicles, leading to the 2006 documentary, "*Who Killed the Electric Car?*" [1]

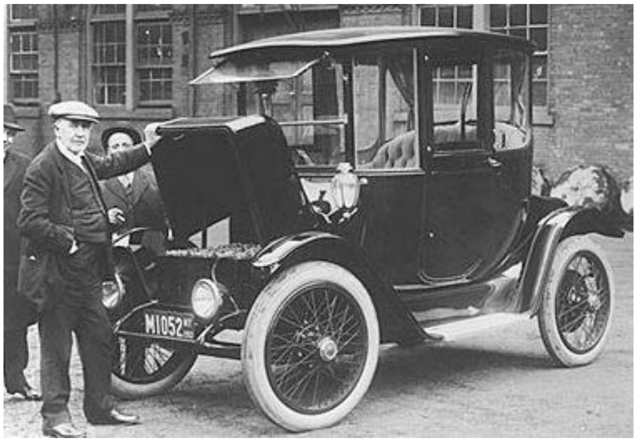

Figure 1. Thomas Edison with the 1912 Detroit Electric

As the new century dawned, however, the EV finally seemed to have real prospects as researchers scaled up energy-dense battery technologies from handheld consumer devices to make viable power sources for EVs, whether hybrids or ‘pure’ electrics. As has happened in several markets since the mid-1990s, nickel-metal hydride batteries appeared first, including in the Toyota Prius, only to be displaced by the superior characteristics of Li-ion technology. Now we are seeing the Chevy Volt PHEV and the Nissan Leaf EV striving for market share along with a host of exotic and not-so-exotic battery-powered vehicles.

THE STIMULUS

Amid the run-up in gasoline prices in 2009 and the severe recession that hit the US economy, the Obama administration decided to boost the chances for EVs by introducing the Advanced Vehicle Battery Manufacturing Initiative of the American Recovery and Reinvestment Act (ARRA) – the Stimulus Act. This $2.4 billion initiative included $1.5 billion for US-based manufacturing of advanced batteries and their components, as shown in Table 1. (Although some have decried such stimulus funding as government waste, this funding is well below the subsidies received by the oil and gas industry every year.)

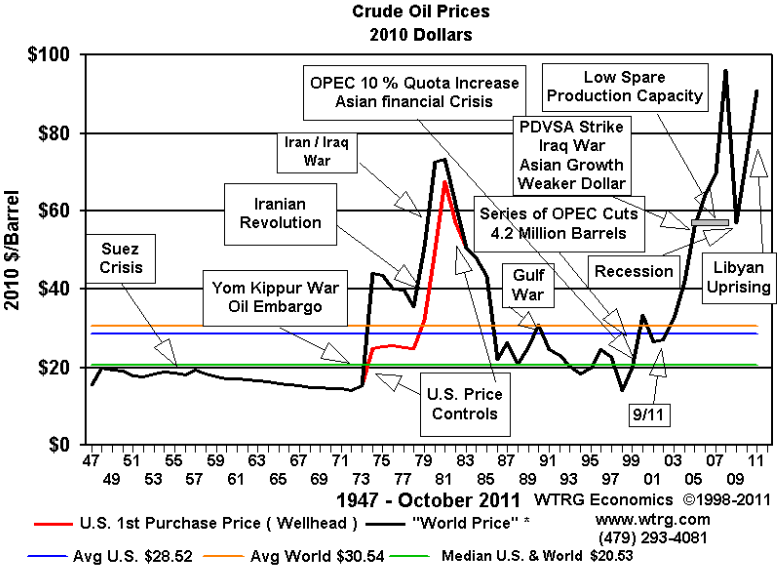

Figure 2. Historical oil prices in 2010 dollars (from WTRG Economics)

Table 1. ARRA battery manufacturing awardees

Awardee	Amount ($ million)	Technology
Johnson Controls-Saft	$299.2	Lithium-ion cells and batteries
A123 Systems, Inc.	$249.1	Lithium-ion cells and batteries
KD ABG MI, LLC (Dow Kokam)	$161	Lithium-ion cells and batteries
Compact Power, Inc. (on behalf of LG Chem, Ltd.)	$151.4	Lithium-ion cells
EnerDel, Inc.	$118.5	Lithium-ion cells and batteries
General Motors Corporation	$105.9	Lithium-ion battery assembly
Saft America, Inc.	$95.5	Lithium-ion cells and batteries
Exide Technologies with Axion Power International	$34.3	Advanced lead-acid
East Penn Manufacturing Co.	$32.5	Advanced lead-acid

The good news for the awardees was that the grants covered 50% of the cost of the new facilities. The bad news was that these were 50% grants—and these companies had to fund the remaining 50% either directly themselves or from other sources. This was not a problem for financially strong companies but placed a significant burden on others. Already we have seen that Ener1, the parent of Enerdel, filed for Chapter 11 bankruptcy in January 2012. A court approved their restructuring plan and they emerged from bankruptcy protection in March, but the underlying market issues remain. There are two linked problems faced by companies like Enerdel: the first is the timing of EV adoption by car buyers; the second is a more fundamental issue involving physics and dollars.

EV ADOPTION

Looking at the second problem, a typical HEV battery such as that of the Prius is on the order of 1.5 to 2 kilowatt-hours, and the combined cost of the battery and parallel electric drivetrain adds a few thousand dollars to the price but does not put the vehicle out of reach of most car buyers. However, an HEV provides little or no electric-only driving capability and certainly no possibility of being able to divorce oneself from the gas pump. That possibility only begins to emerge as we move from HEVs to plug-in vehicles such as PHEVs. Using the rule-of-thumb for a range of approximately 4 miles per kilowatt-hour of battery energy, a PHEV with a 40-mile electric-only range must have around 10 kWh of usable energy plus some residual energy, about 30% of the total, for operation in hybrid ‘range-extender’ mode. This works out to something like a 15 kWh battery, creating a cost adder for the battery and electric drivetrain well into five figures, thus limiting the available market for the vehicle, even after government incentives are taken into account. This was confirmed in March 2012, when GM announced that production lines for the $42k Chevy Volt would be stopped for five weeks because of slow demand.

The cost problem is worse for pure electric vehicles. Granted, such vehicles do not have to cover the cost of an alternative gasoline-powered drivetrain, as with hybrids, but the battery size must be much larger in order to provide a sufficient range, and this adds significantly to the vehicle cost. Nissan has managed to keep its Leaf EV in range of many buyers ($32k, before incentives) by limiting the vehicle to a 24 kWh battery, providing an official EPA range of only 73 miles—and this range varies considerably according to driving conditions; Nissan itself states a range of 47 to 105 miles. Such numbers will do little to overcome the ‘range anxiety’ that many prospective buyers will feel.

So what we see is that HEVs have mass-market appeal, while PHEVs and EVs have more of a cost burden to overcome, causing adoption to be slower. This issue will ultimately resolve itself as long-term prices fall, but the short-term problem for battery manufacturers is that it takes an awful lot of 2 kWh HEV batteries to fill a factory sized for many hundreds of megawatt-hours of annual production.

MAKING UP THE VOLUME

So how will the battery manufacturers fill their shiny new factories? One possibility that is finally emerging is the energy storage market. Once the domain for technically interesting but ultimately one-off systems such as the Golden Valley Electric Association Battery Energy Storage System (GVEA BESS) described in Battcon 2002[2], energy storage is achieving regulatory and customer acceptance, and standardized products are starting to appear, such as containerized 'megawatt in a box' Li-ion systems such as that shown in Figure 3. The Federal Energy Regulatory Commission has ordered US grid operators to open their markets to alternative resources such as energy storage systems, and battery-based systems for regulation service are being installed with increasing frequency. In a particularly audacious move, the New York Times reported in a blog post[3] that utility offshoot AES Energy Storage had responded to a Long Island Power Authority request for proposals for new generating capacity by proposing 400 MW of battery storage with a four-hour run time.

The energy of just one such system is equivalent to around a million HEV batteries, and even if this particular proposal is unsuccessful there are many who believe that the energy storage market will outstrip the EV battery market, at least in the short-to-medium term. In fact, most of the players in the EV battery market have already made some sort of foray into the energy storage arena.

Having said that, the energy storage market is still in the early stages of its emergence, and the funded Li-ion factories are coming on-line now. While the more financially secure companies can afford some leaner years before their new factories become profitable, those whose accounts have been stretched thin by the new plant expenditures cannot afford to wait and must find new sales wherever they can. Such companies could start promoting their batteries aggressively into standby markets.

Figure 3. Containerized Li-ion energy storage system

CAVEAT EMPTOR

In recent Battcon papers the author has discussed the suitability of Li-ion batteries for standby applications (2010)[4] and has highlighted the need for users to conduct a careful and thorough evaluation of new battery technologies that they may be considering (2011)[5]. The 2010 paper highlighted the need to adopt a particular architecture with Li-ion batteries, notably with multiple parallel strings, to mitigate failure of electronic monitoring and control systems that must be used with this technology. Such architecture is commonly used in telecom power systems and also in larger UPS systems, but would be a radical departure from the norm in utility substations, for example. The subject of the 2011 paper was IEEE Std 1679-2010[6], which provides a framework for manufacturers to present data characterizing their batteries and for users to evaluate those products.

The verdict for Li-ion in standby applications is that there are potentially significant benefits in some applications and pitfalls in others. Moreover, there are huge differences in the approaches that manufacturers are taking in the design of Li-ion systems, so the suitability of one Li-ion product for a particular application does not guarantee the compatibility of another.

This is truly a case of *caveat emptor* – let the buyer beware. Even so, properly designed Li-ion batteries using suitable electrochemistries can provide compelling advantages in many applications, and the concept of a self-diagnostic battery can be extremely attractive to a user with a limited maintenance budget. Furthermore, the price of Li-ion batteries will fall as production volume for large-format cells increases, making these products still more attractive.

This should not, however, be seen as the beginning of the end for lead-acid and nickel-cadmium batteries. As discussed in the 2010 paper[4] traditional batteries will remain viable for many years to come. It is highly likely that lead-acid batteries will continue to have lower initial cost than their Li-ion counterparts; while in applications requiring absolute reliability it will be difficult for Li-ion batteries to best Ni-Cd types. For example, there are mountaintop applications where access in winter is possible only by helicopter and where the cost of an unscheduled maintenance visit can exceed the cost of even the most expensive battery; in such cases the ability to function well at all temperatures without the need for failure-prone electronics makes Ni-Cd a better choice than Li-ion. This situation well illustrates the double-edged nature of Li-ion electronics; on the one hand they make the batteries self-diagnostic and free from routine maintenance, while on the other they are the main source of unreliability in these systems.

LITHIUM SHORTAGE?

With the prospect of eventual widespread adoption of EVs, large deployments of energy storage systems in the electricity network and Li-ion taking significant volume over time in the standby market, some researchers have raised the specter of lithium shortages, saying that the US would free itself from oil from the Middle East, only to become dependent on diminishing lithium resources in South America. This theme originated with a paper in December 2006 by energy analyst William Tahil with Meridian International Research entitled “The Trouble with Lithium: Implications of Future PHEV Production for Lithium Demand.”[7] Tahil’s claims were soundly debunked by R. Keith Evans of the US Geological Survey, who published a two-part paper in 2008 and 2009: “An Abundance of Lithium”[8] and “Lithium Resources: Are They Adequate?”[9] The sparring between Tahil and Evans, as well as an in-person evaluation of various mining operations and lithium deposits around the world, is summarized in an excellent book by Seth Fletcher, “Bottled Lightning: Superbatteries, Electric Cars, and the New Lithium Economy.”[10] After studying this book, the reader is left in no doubt that lithium supplies will continue to be abundant for many years to come.

IS LI-ION THE END GAME?

It is tempting to ask, is Li-ion the end of the battery development road, with nothing better in sight? The answer to this question is a resounding NO. In today’s battery world there is no shortage of competitors to Li-ion, including various flavors of flow batteries, high-temperature batteries based on molten sodium, and many others. Some of these technologies are in the early stages of commercial production while others are still in the laboratory, with claims of future performance, based on small-scale sample tests, that are more for the consumption of venture capitalists than prospective users.

Even in the field of lithium batteries, Li-ion could eventually be surpassed. The dream technology for researchers is lithium-air, in which lithium metal and oxygen from the air are combined to give stupefying specific energy numbers; the theoretical maximum specific energy of Li-ion technology is around 400 Wh/kg, while that of lithium-air is 11,000 Wh/kg. If a capable lithium-air battery could be produced with even a modest fraction of that theoretical number it could easily displace gasoline as an energy source for vehicles. Getting to a commercial product, however, will take enormous efforts over many years, and success is by no means guaranteed. Various metal-air technologies exist already, but they are primary batteries and are non-rechargeable. Achieving the ability to cycle hundreds or thousands of times is one of the holy grails of metal-air researchers.

So Li-ion is certainly not the end game, either today or in the future; but it is an extremely capable group of technologies that are likely to see continued incremental improvements in energy density, operating life, safety and cost in the coming years.

CONCLUSIONS

There can be no doubt that electric vehicles, whether hybrids, plug-in hybrids or pure EVs, are here to stay; so too are the lithium-ion batteries that will power them. Government funding has created a US-based Li-ion industry that otherwise might not have emerged for several years, if ever. But the combined capacity of that industry is likely to exceed EV requirements for some years to come, and those manufacturers will be looking elsewhere, including the standby battery market, to fill their factories. Li-ion batteries can certainly offer attractive benefits in a number of standby market sectors, but the onus will be on users to make a careful and thorough evaluation of the suitability of a particular Li-ion product for their application, and whether the manufacturer is likely to remain in business over the coming years to provide service and spare parts for their batteries. Not all applications are well-served by Li-ion, and today's lead-acid and Ni-Cd batteries will remain viable alternatives to the new technologies well into the future.

REFERENCES

1. *Who Killed the Electric Car?* Official website, http://www.whokilledtheelectriccar.com/
2. DeVries, T, *The GVEA BESS: Choosing a Multi-Million Dollar System*, proceedings of Battcon 2002
3. Wald, M, *Can Batteries Replace Power Generators?*, May 18, 2011 posting at http://green.blogs.nytimes.com/2011/05/18/can-batteries-replace-power-generators/#
4. McDowall, J, M. Lippert, *Sophistication Versus Simplicity: System Design Considerations for Lithium-Ion Batteries in Standby Power Applications*, proceedings of Battcon 2010
5. McDowall, J, *Comparing Apples and Oranges: Guidance on the Adoption of New Technologies*, proceedings of Battcon 2011
6. IEEE Std 1679-2010, *IEEE Recommended Practice for the Characterization and Evaluation of Emerging Energy Storage Technologies in Stationary Applications*
7. Tahil, W, *The Trouble with Lithium: Implications of Future PHEV Production for Lithium Demand*, posted online, December 2006
8. Evans, R.K., *An Abundance of Lithium*, posted online, March 2008
9. Evans, R.K., *Lithium Resources: Are They Adequate?*, posted online, January 2009
10. Fletcher, S, *Bottled Lightning: Superbatteries, Electric Cars, and the New Lithium Economy*, Hill & Wang, May 10, 2011