B-LAB: CHANGING THE GAME FOR LEAD ACID

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SYNOPSIS

In the West, Lead Acid Batteries are often viewed as being at the end of their development cycle and are often overlooked for a number of important emerging markets such as grid scale storage and urban EV's. Yet when measured by production capacity, lead acid remains dominant, capturing more than 98% of all new rechargeable battery production.

For many years, various researchers have investigated an alternative "Bipolar" architecture for lead acid batteries which could offer fundamental and significant performance, cost and other advantages over conventional monopolar designs. However, technical, cost and other challenges have limited the practical applications of this bipolar architecture.

AIC and East Penn Manufacturing are collaborating on a novel technological approach to bipolar lead acid batteries (B-LAB). After extensive development this technology has been validated and shown to deliver reduced mass, increased cycle life and the elimination of internal connectors and associated "Top Lead". Importantly, this B-LAB technology is compatible with existing lead acid production and recycling infrastructure and has the potential to offer system level energy density which is equivalent to current commercial lithium ion based systems.

This paper summarizes the key features, performance and manufacturing economics of B-LAB, which are compared to Li-ion for stationary and light duty urban EV's.

TERMINOLOGY AND DISCLAIMER

- For the purposes of clarity, throughout this paper, the acronym B-LAB will be used to the specific and proprietary bipolar lead acid technology developed by AIC.

- This paper and the accompanying presentation include various data and analyses which AIC has researched, developed and or derived for its own use. It is reproduced here without additional reference and no warranty is given or implied as to its source or accuracy.

INTRODUCTION

Monopolar and bipolar lead acid batteries

Commercial Lead Acid Batteries (LAB) are constructed using a format in which each electrode is either positive or negative. Positive and negative electrodes are paired and connected using what is often referred to as “Top Lead”. This architecture is technically ‘monopolar’; however, the ubiquity of this arrangement is such that this terminology is rarely used.

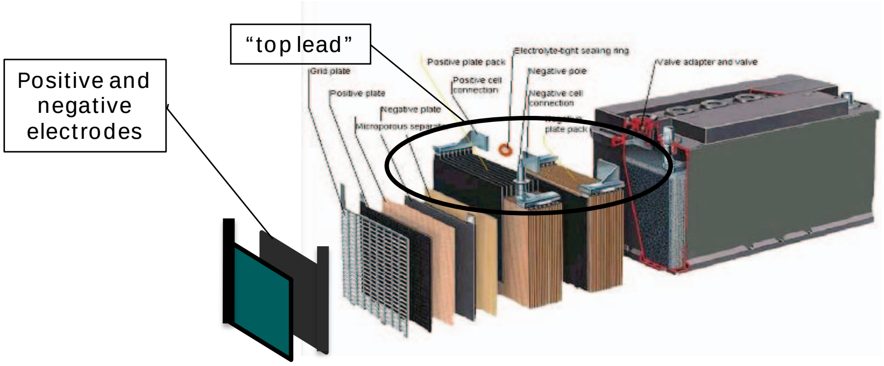

Figure 1 – Monopolar layout of a conventional lead acid battery

There is an alternative “bipolar” arrangement, in which each electrode has one side that is positive and one that is negative. Bipolar batteries are configured such that each positive face is paired with a negative face. In operation, current passes through the faces of the electrodes without the need for top connectors.

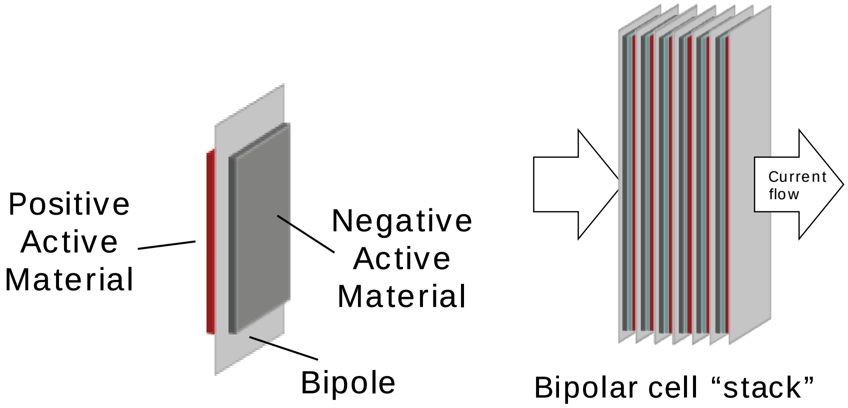

Figure 2 – Illustration of a bipolar layout

This arrangement has the potential to offer a number of significant benefits over monopolar construction, including:

- reduced mass and thus increased gravimetric energy density
- a less restrictive current path and more uniform distribution of potential across the face of the active material
- lower internal resistance
- the ability to readily construct batteries in high voltage configurations (e.g. 24, 48, 60V)

It is believed that this bipolar arrangement was first invented by Pytor Kapitsa in the UK during the 1920’s to deliver short bursts of very high power for his experiments in high energy physics.

In the decades following Kapitsa's pioneering work, bipolar lead acid batteries have been the subject of numerous academic and industrial research efforts around the world. However, a bipolar configuration requires the separation of the negative and positive active materials within a single plate. In turn this requires a bipolar substrate with exceptional properties (e.g. corrosion resistance, structural stability, compressive strength), which then introduces new technical challenges such as active material adhesion and sealing. Despite some well funded and intense research efforts during the 1940's, 1960's, 1980's and now, bipolar lead acid batteries have not yet proven capable of meeting the demands of commercial manufacture and reliable long term operation.

WHY FOCUS ON LEAD ACID?

Established scale of production and recycling

Given recent advances in battery technologies, it is often assumed that the lead acid industry is in its twilight, on the cusp of being replaced by lithium-ion and/or other chemistries. Looking at the global production of secondary (i.e. rechargeable batteries) we have estimated that Li-ion now accounts for almost 30% of new batteries by value. Similarly, our analysis of various recent funding for battery research indicates that Li-ion dominates battery R&D. Indeed, for almost a decade it was virtually impossible to attract research funding for battery chemistries that were not based on lithium.

However, there are some interesting analyses that receive little attention. First, we reworked the reported battery production numbers by the total capacity of batteries produced. This eliminates the bias resulting from the large price disparity in which a small Li-ion laptop battery is equivalent in price to a lead acid based automotive starter battery. On this basis, our data indicate that upwards of 98% of all rechargeable batteries produced in 2009, were lead acid, when ranked by the combined energy capacity of batteries produced.

One related and key feature of lead acid batteries is the scale of recycling. Currently, the lead acid battery industry recycles nearly 100% of its product. This places the lead acid industry at the top of all recycling indices. By comparison, the aluminum industry is a distant second with between 40 and 60% of its product recycled. By contrast, despite more than a decade of volume production, high volume commercial recycling facilities for Li-ion batteries do not yet exist.

Scale up costs

After evaluating production scale, we conducted a separate analysis of the relative cost of building new manufacturing facilities. Currently, Li-ion manufacturing facilities cost in the range of $650,000 - $1,500,000 per MWh/year of production capacity. The dominant Li-ion product is the '18650' cell which is produced in exceptionally high volumes for markets as diverse as laptop computers to Tesla's roadster. Given the established volume of this production, we find it difficult to see where capital cost reductions for Li-ion facilities may be achieved.

Our analysis of sodium sulfur (NaS) and nickel metal hydride (NiMH) production facilities indicated similar costs ($500,000-1,000,000/MWh/yr. Meanwhile our data for conventional lead acid manufacturing facilities indicates a capital cost in the range of $50,000-80,000/MWh/year of production capacity. Consequently it is twenty times less expensive to build a lead acid production facility than to build a Li-ion or NaS production facility of equivalent production capacity.

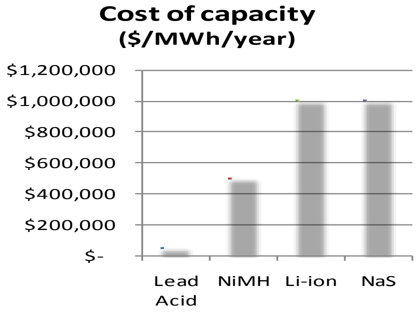

Figure 3 – relative cost of battery production facilities

Untapped storage capacity

The relative scale, recycling and low cost of lead acid production facilities, is very attractive. However this is of little importance if lead acid is to be eclipsed in performance by Li-ion or other chemistries.

Putting cost aside, for transport applications, the gravimetric energy density (kWh/kg) is the defining characteristic. With an energy density of more than 40MJ/kg, lithium metal is approximately equal to jet fuel and more than twenty times that of metallic lead. This basic fact has been the driver for interest and funding of R&D in lithium chemistries.

However, Li-ion batteries are not made solely out of lithium, just as lead acid batteries do not contain just lead. Each needs to be part of a complex formulation and configuration involving electrolytes, additives, alloys etc. Because of their relative positions in the Periodic Table, lead is combined with elements which are less dense than it (C, S, O, and H) and lithium is combined with elements which are denser than it (P, C, F, Fe, Mn, Co). The net effect is a convergence in gravimetric energy density at the active material and cell level.

Currently, high quality commercial Li-ion batteries are capable of delivering 150-200Wh/kg at the cell level. Fully compounded active material in a lead acid battery have a theoretical energy density of 120-150Wh/kg. So at the per-cell level, the gap in gravimetric energy density between lithium and lead in theory, is potentially small.

However, when configured as a conventional multi-cell monopolar battery the energy density of lead acid is reduced to 30-40Wh/kg. This is in part due to the need for heavy top lead connectors to join the individual cells in a monopolar lead acid battery. It is also a feature of the relatively low utilization (30-40%) of active material in a conventional lead acid battery.

In addition, further consideration must be given to the energy density advantage of Li-ion as a fully configured system. High capacity Li-ion batteries intended for motive power applications require structural, thermal management, ant-intrusion, charge management and other components as part of a total Battery Energy Storage System (BESS). These requirements arise from fundamental features of commercial lithium chemistries and these are either not required or greatly simplified for lead acid batteries.

By combining published and unpublished data for a range of electric vehicles, we were able to generate the following analysis of current System Level energy density for vehicle BESS.

In the 1990’s, GM’s EV1 achieved a System Level energy density of 31Wh/kg for its lead acid based BESS. Separately, the current size of the Chinese e-bike fleet is between 130 and 150 million vehicles. These 1-3kW scooter-class vehicles are almost 100% lead acid powered and the System Level energy density of an e-bike BESS is currently 40Wh/kg.

The above system level capacity figures for lead acid based vehicle BESS compare well with the 44Wh/kg System Level energy density of the NiMH BESS in Toyota’s Prius. However the biggest surprise was that the first System Level data released by GM for its Volt indicated a System Level energy density of 50Wh/kg. For comparison our early calculations of the energy density of a B-LAB indicated 50Wh/kg, simply from the reduced lead content.

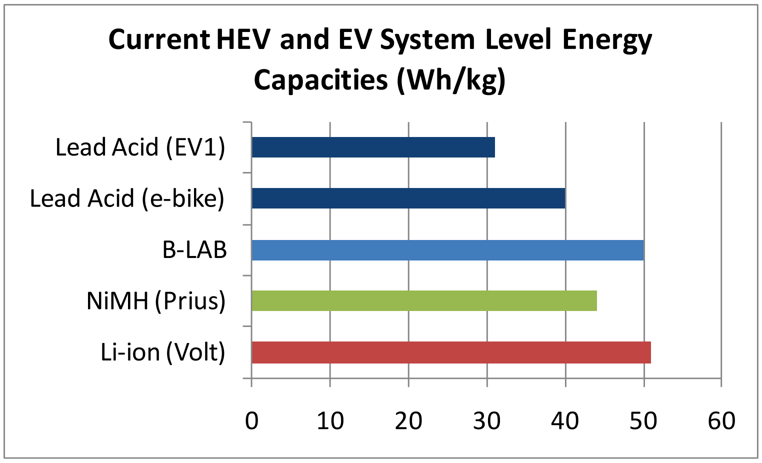

Figure 4 – System level energy densities

Consequently, we believe that there is significant untapped capacity potential for lead acid chemistry, both at cell level and System Level. A bipolar architecture is well placed to access this potential both through a significant reduction in inactive materials and through better utilization of active materials.

B-LAB: A STEP CHANGE IN LEAD ACID TECHNOLOGY

Bipolar lead acid

As noted earlier, bipolar lead acid batteries are not new and a number of entities are active in this field. These typically focus on the bipole and employ unconventional and proprietary materials to meet the requirements of corrosion resistance and material adhesion. In turn these require raw materials and manufacturing processes which are outside the range of those employed in conventional lead acid manufacture.

AIC's B-LAB Technology

Our approach has been significantly different from other bipolar lead acid programs. As outlined above, one key feature of the lead acid industry is the scale of its manufacturing and recycling capabilities. We believe that the ability to leverage this established infrastructure is a critical starting point upon which to build on the inherent advantages of bipolar architecture.

Consequently, our goal was to develop a bipolar technology capable of being implemented in conventional lead acid manufacturing facilities. To this end we focused on materials and methods which are compatible with modern, best practice lead acid manufacturing and sought wherever possible to streamline and reduce manufacturing process.

Our research and development effort spanned approximately 15 years and employed a diverse and multi-disciplinary team. The program was funded entirely by AIC at a cost of more than $10 million. Numerous ideas and approaches were explored and a significant body of knowledge involving bipolar batteries based on lead acid and other chemistries has been established.

By mid 2009, we had developed tested and validated robust prototypes and began seeking commercial partners. In January 2010 we formed a commercial relationship with East Penn Manufacturing Co., Inc., to manufacture B-LAB's for markets in North America and NAFTA territories.

At the core of our B-LA technology is a family of proprietary materials and coatings which form the basis of the bipole. To this we have developed a range of proprietary bipole seals, methods of construction and separators optimized for the bipolar architecture. These are compatible with existing lead acid production methods and each may be configured as required to deliver a broad range of performance characteristics. Figure 5 illustrates the simplicity and elegance of this architecture.

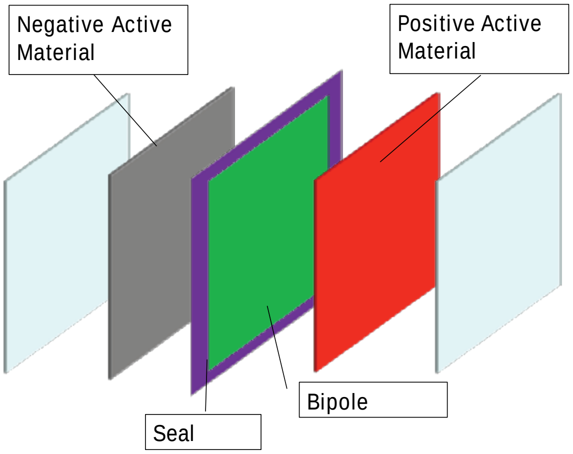

Figure 5 – Exploded diagram of bipolar cell components

The first B-LAB products utilize lead acid chemistry which is similar to that used in conventional valve regulated lead acid batteries.

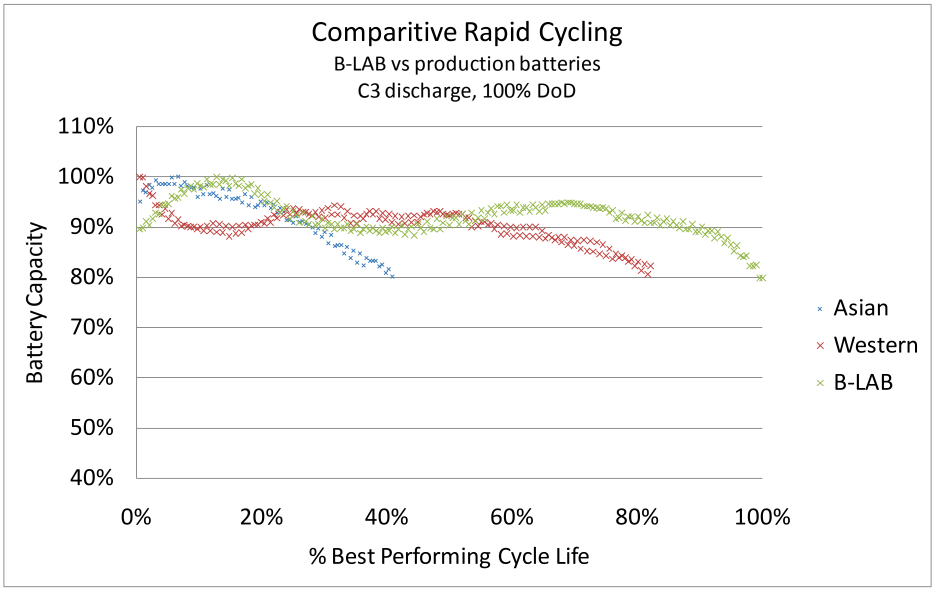

Figure 6 – Cycle life at 100% DoD and aggressive charging

Figure 6 compares an early prototype B-LAB with conventional lead acid batteries using equivalent chemistries. All were discharged at C3 to 100% DoD and cycle life was determined by a reduction in actual capacity to 80% of rated capacity. The prototype B-LAB delivered significantly higher cycle life than established high quality conventional lead acid products.

Other benefits of B-LAB include high cell and system level energy density, rapid charging capability and high resistance to physical shock and vibration.

SUMMARY

In summary, the lead acid industry is uniquely placed in terms of established manufacturing scale, inexpensive expansion and near 100% recycling, to become a major player in emerging and high growth markets such as motive power and stationary storage.

Its challenge has been to meet the energy density of more recent chemistries such as Li-ion. However, looked at from the perspective of System Level energy density, conventional (i.e. monopolar) lead acid batteries are not as far behind as is often assumed.

B-LAB represents a step change to the architecture of a lead acid battery which delivers significant improvements over monopolar lead acid batteries which include:

- Higher gravimetric energy density by eliminating the top lead required by monopolar batteries;
- Higher cycle life;
- Reduced charging time;
- A simplified and more direct current path;
- Higher resistance to shock loads and vibration through better support of the electrodes.

At the same time, B-LAB is compatible with existing production facilities and offers significant reductions in manufacturing process steps and materials used. On this basis, we believe that B-LAB delivers an important tool in the advancement of the lead acid industry.