Conference Program

2nd Annual International Conference

Battery Safety 2011

November 9-10, 2011 • Las Vegas, NV USA

Advancements in Systems Design, Integration & Testing for Safety & Reliabilty

Widely publicized safety incidents and recalls of lithium-ion batteries have raised legitimate concerns regarding lithium-ion battery safety. Battery Safety 2011 is conveniently timed with Lithium Battery Power 2011 and will address these concerns by exploring the following topics:

- Application specific battery safety issues affecting battery performance
- Major battery degradation and reliability factors
- Battery management systems
- Commercial cells evaluation and failure analysis
- Advances in testing techniques and protocols
- High throughput testing, automation and modeling for better safety
- Standardization & Regulatory issues

Conveniently timed with

7th Annual
Lithium Battery Power 2011

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2nd Annual International Conference

Battery Safety 2011

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Nothing can substitute the benefits derived from attending **Battery Safety 2011**. But if your schedule prevents you from attending, this invaluable resource is available to you. *Note: Documentation is included with conference fee for registered delegates and live and on demand webcasts are available for download.*

Conveniently timed with another special event

7th Annual International Conference

Lithium Battery Power

November 7-8, 2011
Las Vegas, NV USA

Wednesday, November 9, 2011

8:00 *Registration, Exhibit Viewing/Poster Setup, Coffee and Pastries*

8:50 **Organizer's Welcome and Opening Remarks**

9:00 **Lithium-Ion Battery Safety: Issues and Solutions**

Ralph J. Brodd, PhD, Director, Kentucky-Argonne Battery Manufacturing Research and Development Center

An overview of the safety issues will be presented from the point of view of the chemistry, manufacturing and application in electronic as well as transportation applications. The major cause of safety incidents in batteries for electronic applications has been related to manufacturing defects in the materials and cell assembly. These are of the order of one incident in 5 million cells. New applications for electric and hybrid vehicles require a significant improvement in cell reliability by an order of magnitude over present practice as well as a means to isolate problem cells from the main stream in a battery pack. These and other issues to mediate problem cells will be discussed

9:30 **Breakthrough in Large-Format Li-ion Battery Safety through Computer Simulation**

Chao-Yang Wang, PhD, Distinguished Professor of Mechanical, Chemical, & Materials Science and Engineering, Director, Electrochemical Engine Center (ECEC), Co-Director, Battery & Energy Storage Technology (BEST) Center, The Pennsylvania State University

Currently whether or not a battery is safe is assessed by a set of abuse tests that are not as sensitive and accurate as they should be. We at Penn State ECEC, working with engineers at EC POWER as part of the DOE CAEBAT program, have developed computer models and tools to simulate processes of nail penetration, internal shorting, and thermal runaway in automotive Li-ion batteries with complex geometries. We shall show effects of nail diameter and penetration speed during partial or full penetration, location of shorting, and cell capacity on safety characteristics. We highlight fundamental insight into safety events and propose safety-enhancement strategies. Combined with experimental validation, computer simulation offers a possibility to design inherently safe batteries for automotive applications.

10:00 **Abuse Tolerant Lithium-Ion Cells for Transportation Applications**

Christopher J. Orendorff, PhD, Power Sources Technology Group, Sandia National Laboratories

Abstract not available at time of printing. Please visit www.KnowledgeFoundation.com for the latest Program updates.

10:30 *Networking Refreshment Break, Exhibit/Poster Viewing*

11:00 **Safe Li-Ion Technologies for Transportation and Energy Storage**

Karim Zaghib, PhD, Team Leader - Li-Ion Battery, Energy Storage and Conversion, Hydro-Québec Research Institute (IREQ), Canada

Hydro Quebec has tested several Li-ion battery technologies using the following electrode materials: $LiCoO_2$, $LiMn_2O_4$, $LiCo_{0.33}Ni_{0.33}Mn_{0.33}O_2$ and $LiFePO_4$ versus the graphite or $Li_4Ti_5O_{12}$. We will demonstrate the results of the safety tests (crash, nail penetration, short circuit, etc.) performed on these batteries. The ARC and DCS methods were used to study the safety of charged cathode materials and lithium intercalated anode materials. Among the tested systems, the batteries based on LiFePO4 are found to be the safest systems for the transportation and energy storage.

11:30 **Safety of Lithium-Ion PHEV Cells: Cylindrical versus Prismatic**

Brian M. Barnett, PhD, Vice President, TIAX LLC

The occurrence of safety-related field-failures has prompted large-scale recalls of lithium-ion battery packs in consumer applications. The severity of field-failures is forcing the industry and the research community to adopt new approaches to tackle safety. That is especially the case when even larger lithium-ion cells are being considered for transportation applications. For PHEV scale cells, there has been considerable debate regarding the relative merits of cylindrical versus prismatic (and pouch) cells with regard to safety, as well as performance. We have used simulations, supported by experiments, to help set a quantitative framework for consideration of relative safety of large format cylindrical and prismatic cells, and to help understand the conditions that favor thermal runaway following development of an internal short, the latter being the most frequent cause of safety incidents. Results for the relative safety of cylindrical and prismatic 33 Ah cells are presented and described. We also discuss the implications of these results for materials selection and consideration of various cell designs.

12:00 **Working Toward a Fail-Safe Design for Large Capacity Lithium-Ion Batteries**

Gi-Heon Kim, PhD, Kandler Smith, PhD, and Ahmad Pesaran, PhD, National Renewable Energy Laboratory

Lithium-ion batteries (LIBs) are believed to be a promising candidate for electric energy storage of electric drive vehicles due to their high power and energy density. However, violent incidents reported for this technology and consequent safety concern are the major obstacle for fast market acceptance of

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LIB powered electric vehicles. High temperature triggers exothermic decompositions of LIB components often resulting in violent failure of the system, known as thermal runaway of LIBs. Mature small capacity LIBs, used in applications such as consumer electronics and power tools, typically incorporate multiple layers of safety incident mitigation methods. LIBs for vehicle applications should be much larger in capacity and physical size than those for consumer electronics. Scaling-up of LIBs dramatically changes the responses of LIB system under safety incidents. Consequently, protection/mitigation technologies for small cell system against safety incidents, such as positive temperature coefficient (PTC), current interrupt device (CID), and shutdown separator, do not work properly with large format LIB cells. This paper will introduce NREL's recent model/experimental investigation for a safety enhanced large battery design with features enabling early fault detection and electrical isolation of a fault.

12:30 *Luncheon Sponsored by the Knowledge Foundation Membership Program*

2:00 **Navy High Energy Power Source Platform Integration - Recent Initiatives and Results**

Clinton Winchester, PhD, Group Leader & Senior Technologist, Naval Surface Warfare Center (NSWC)*

The Navy will be using advanced power sources in various payloads and platforms. These advanced power sources provide higher energy density and greater power density than traditional sources (e.g. Pb-Acid batteries) and the capability benefits come with definable hazards and potential risks. The Navy has undertaken to establish a broader aspect of hazard assessment based on MIL-STD-882 for electrochemical power sources (batteries, capacitors, fuel cells) and hybrid systems based on these components. We will describe the current instructions and guidance, results from recent characterization tests, and general findings and explicabilities to portable and embedded systems. **In collaboration with: J.Schwartz, D.Fuentevilla, E.Rule, E.Shields*

2:30 **Lithium Ion Failure Rates and Fire Protection Considerations**

Celina J. Mikolajczak, PE, Senior Managing Engineer, Exponent

Lithium-ion battery technology has become endemic to the consumer electronics industry and is finding new applications in industrial and transportation sectors. As lithium-ion batteries get larger and are used to store greater amounts of energy, there is interest in assessing the risk of failure, developing strategies for failure mitigation. We will discuss failure modes and failure rates associated with un-used lithium-ion batteries (i.e. new batteries in storage, or in transit to end users) compared to failure modes and failure rates of batteries that have been placed into service. Then we will discuss some considerations for fire protection under these varying scenarios.

3:00 **Challenges for Safety Standards for Lithium-Ion Cells**

Mahmood Tabaddor, PhD, Research Manager, Predictive Modeling and Risk Analysis Group, Corporate Research, Underwriters Laboratories Inc.

Safety Standards help promote the safe commercialization of products. However, in some cases such as with lithium-ion cells, when the technology is developing so fast and an understanding of potential failure modes is still an active area of research, there is a tremendous challenge to updating the safety standard. Tests that may show promise in a laboratory setting providing battery designers and researchers insights may not translate well as a new test for a safety standard. This presentation will describe the search for a new test method for battery safety standards to help address field failures of lithium-ion cells attributed to thermal runaway due to internal short circuit.

3:30 *Networking Refreshment Break, Exhibit/Poster Viewing*

4:00 **Active Thermal Management of Lithium Ion Batteries Using Flexible Graphite Heat Spreaders**

Jonathan A. Taylor, R&D Engineer, Advanced Energy, GrafTech International

Thermal management systems promote excellent performance, durability and safety in large lithium ion batteries, but often add weight, volume, complexity, parasitic power consumption and cost to the system. Flexible graphite has a unique combination of properties that enable compact, lightweight, thermal solutions. In this paper, a flexible graphite-based active thermal management solution for prismatic lithium ion batteries is presented. The inventive design effectively manages cell temperatures despite being more lightweight and compact than conventional liquid-cooled systems.

4:30 **Implications of Cell to Cell Manufacturing Variations on Potential Risk of Safety of a Lithium ion Battery**

Shanthi Korutla, PhD, Director, Battery Cells & Advance Product Development, International Battery, Inc.

Safety concerns of lithium ion batteries are becoming more of a focus of the public's attention. This has resulted in the ever increasing commercial use of $LiFePO_4$ due to its intrinsic safety and chemical stability as cathode materials. Large format Li ion cells manufactured with aqueous processing of $LiFePO_4$-based electrodes with a combination of water-soluble binders exhibited excellent tolerance under extremely abusive conditions such as induced short circuit, over discharge, over charge, nail penetration crush test, etc. that add to its superior electrochemical performance in normal use. In an increasing number of definitive parameters for cell selection are being

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used to build more effective Li ion battery pack, traditional parameters such as cell capacity, resistance and self-discharge etc. measurements do not provide enough information for optimum cell selection, particularly for large format cells that must meet high standards of abuse tolerance in addition to superior in electrochemical performance in a normal operation. Electrode and cell manufacturing process parameters plays an important role as well for safety risks. The paper addresses how the impact of cell to cell variation in a battery system affects both electrochemical performance and abuse tolerance behavior.

5:00 **Failure Investigation of Li-Ion Batteries**

Jian Xie, PhD, Professor of Mechanical Engineering, Lugar Center for Renewable Energy, Indiana University - Purdue University Indianapolis (IUPUI); and
Yang Ren, PhD, X-Ray Science Division, Argonne National Laboratory

Lithium ion batteries (LIBs) have the highest specific energy and energy density among the different battery technologies. This high specific energy and energy density are desired for many applications, but are the potential causes of safety incidents, which could cause detrimental damage to valuable property and could even cost human lives. Therefore, the safety of LIBs is of a great importance to their application in portable electronics, electric and hybrid electric vehicles, and military devices and systems. To maintain safe operation of a LIB cell, it is necessary to monitor the state of health of that cell. In order to do so, LIB failure needs to be comprehensively investigated including failure modes, failure causes, signs of early failure, detection methods to catch early failure signs, etc. Then, a system should be developed to monitor the LIB state of health. We have formed a team of government, academia, and industry professionals to investigate the failure of LIBs. A comprehensive and systematic approach has been taken to study the failure mechanism. A synchrotron high-energy X-ray coupled with electrochemical testing was used to study the in situ structural changes of the electrode materials during the charge/discharge cycle. The anode MCMB was found to have a new phase of Li and C compounds formed after overcharge as well as a possible Li deposition. The in situ structural changes of the cathode were also studied. When over-discharging, the corrosion of the Cu current collector was found to be the major cause of LIB failure. The failure mechanism of $LiFePO_4$ cell under overcharge and over discharge conditions have been elucidated from our experimental investigation. The signatures of failure have been identified experimentally. The model/algorithm has been developed for early warning detection. A detection system which can detect the early signs of failure has been developed. This work was supported by US Navy Warfare Center.

5:30 **MODERATED DISCUSSION:**

Battery Safety in Perspective: Real World Assessment of the Most Significant Challenges Facing Advanced Li-Ion Cells Commercialization

6:00 *End of Day One*

Thursday, November 10, 2011

8:00 *Exhibit/Poster Viewing, Coffee and Pastries*

9:00 **Thermally Stable Electrolyte for Li-Ion Cells**

Ganesan Nagasubramanian, PhD, Sandia National Laboratories

Thermal instability of Li-ion cells is a key concern that delays their adoption for transportation applications. The pervasive thermal instability mainly stems from the organic electrolytes and that needs to be eliminated for wide-spread use. Several different approaches including addition of fire retardants, ionic liquids, fluoro compounds, etc. have been made to mitigate this propensity, however, only with a limited success. In this talk our results on Hydro Fluoro Ethers to eliminating this hazard will be discussed.

9:30 **Diagnostic Tools Development for Understanding and Monitoring Overcharge**

Corey T. Love, PhD, Materials Engineer, U.S. Naval Research Laboratory

Safe operation of lithium-ion batteries is significantly influenced by charge/discharge voltage boundaries and the stability of electrode/electrolyte interfaces. Three tools are being developed to detect and understand the detrimental effects of overcharging at the electrode and cell level. First, an *in-situ* impedance method shows significant changes in a commercial lithium-ion polymer cell charged above 4.4 V. Second, *in-situ* X-ray absorption spectroscopy detects structural changes and performance losses within $LiFePO_4$ after repeated cycling. Lastly, we probe the solid electrolyte interface in overcharged electrodes using the surface sensitive "Δ" XANES technique. Results will be presented and discussed as part of a broader effort towards the development of diagnostic tools for lithium-ion batteries.

10:00 **Characterization of Battery Materials: A Battery Safety Perspective**

Sanjay Patel, PhD, Director of Analytical Services at Evan Analytical Group (EAG)

A good understanding of the consistency of materials entering the battery manufacturing supply chain is essential, from both a regulatory, scientific and safety perspective. A number of different

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analytical methods are available, many currently in use, to the battery industry for materials characterization for various purposes. The long-term life cycle and performance of a battery pack can potentially be affected by the presence of unwanted impurities in electrode materials. Variation in electrode composition can result in changes to individual cell performance and affect the stability of the entire battery system. With recent demands from the automobile industry for improvements in battery performance together with stringent safety requirements, adequate understanding and successful monitoring of battery raw materials has become important across the industry. This presentation will review a number of different analytical methods, focusing on those that are well suited to the battery industry for monitoring raw materials for production control. Methods are available that simultaneously allow the measurement of a wide range of impurity levels, thus allowing manufacturers or other end users to determine the consistency of their supply chain and identify changes in raw material quality from their supplier or other changes caused at a particular manufacturing stage.

10:30 *Networking Refreshment Break, Exhibit/Poster Viewing*

11:00 Simulated Internal Short Test Work from NASA and Underwriters Laboratories

Judith A. Jeevarajan, PhD, Senior Scientist - Battery Office, NASA Johnson Space Center

NASA has collaborated with UL to define a standard for the simulation of internal short tests. The initial set of tests included testing a set of cells of an 18650 Li-ion cylindrical cell design using a crush test method and analysis of the indentation and cells using CT scan techniques as well as destructive physical analysis. The standard developed will include recommendations on crush rod diameter, rate of displacement of the crush rod, voltage drop limit conditions, state-of-charge of the cells, orientation of the cells, etc.

11:30 Abuse Testing of Lithium Ion Cells: Internal Short Circuit, Accelerated Rate Calorimetry and Nail Penetration in Large Cells (1 - 20 Ah)

Ann Edwards, PhD, Senior Scientist, and Kirby W. Beard, COO, Porous Power Technologies; and David Wood, Wei Cai, Jianlin Li, Hsin Wang, Oak Ridge National Laboratory

Oak Ridge National Laboratory (ORNL) and Porous Power Technologies (PPT) are developing and testing large C/$LiCoO_2$ cells with PPT's advanced separators. Temperature resistant separators with non-woven web reinforcements and high levels of ceramic filler (to 90% wt.) have survived 220 deg. C temperatures and various abuse tests. Internal short circuit testing, using a new ORNL test protocol, has shown survivability under overcharge/compression testing. Additional destructive over-heating (accelerated rate calorimetry) and nail puncture safety tests were also conducted.

12:00 Safety Testing and Live Video of Large Li-Ion Batteries

Jasbir Singh, PhD, Managing Director, HEL Ltd, United Kingdom

Reliable safety testing of larger batteries and battery packs requires new devices that can handle the potential energy release but also provide the necessary precision to allow reliable prediction of performance. Also, many current testing protocols call for video evidence to accompany the traditional data as photographic evidence gives much needed extra insight. Traditional "ARC" type adiabatic calorimeters are not able to meet these demanding needs and this presentation will show data and videos from a custom designed Battery Testing Calorimeter to provide much needed expansion of "ARC" type data including the use of integrated "cyclers" to evaluate charging and discharging limits.

12:30 *Lunch on Your Own*

2:00 The BMS in Focus- Safety, Testing and Operational For Mobile and Fixed Installations

Ken Chisholm, Global Business Director, Vecture, Inc., Canada

The Battery Management System (BMS) is a critical issue in the safe and reliable operation of lithium re-chargeable chemistries. With smaller battery packs the BMS system is a significant cost adder whilst in larger systems such as GRID systems the BMS needs to manage multiple strings and many cells in series, interacting with the main control system, providing data and control signals. Testing the BMS and the battery packs has safety, reliability and cost implications. The test requirements for smaller, and usually much higher volumes, are very different from the test and integration requirements for large format systems. (i) Considering battery management systems (BMS), from small to large format with safety and performance in focus; (ii) Advances in testing techniques: (a) testing the one shot secondary system, (b) large format systems where operator safety and system integration are key requirements; (iii) Contribution of the BMS in data collection for predictive failure analysis and operational profiling; (iv) Mean time to repair (MTTR) in large format modular systems; and (v) High throughput test systems for the BMS and battery pack.

2:30 Battery Management Systems for Industrial Applications

Doug Morris, President, EnerSol, Inc.; presenting on behalf of Lithium Balance A/S, Denmark

The adoption of Li ion battery technology to power industrial machines has driven the need for appropriate battery management and suitable Li Ion cells. The term industrial application is this context refers to the following areas: materials handling; cleaning machines; lifts and aerial devices; utility vehicles. These applications characterize themselves by

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being typically below 120 volts and utilizing relatively large capacity, low cost batteries often operating in harsh environments. Acute price sensitivity is another characteristic of this market. The role of the battery management in this environment is to provide safe battery operation, control of switching circuitry, SoC estimation and charger control. This differs from an automotive application where typically a CAN enabled vehicle control unit would be present to provide the high level system intelligence and logic. The BMS takes on this role providing direct control of the BDU (battery disconnect unit). The safety logic and providing information to the load, such as CAN messages outlining the recommended allowable discharge rate and regeneration rates from and to the battery at any given time may be required in some applications, in others where there is no CAN bus present the system still needs to provide SoC information, signaling and control to external devices such as chargers.

3:00 *Networking Refreshment Break, Exhibit/Poster Viewing*

3:30 **How to Test & Certify Electric Vehicle Supply Equipment (EVESE) for North America**

Tom O'Hara, Intertek

You've designed your EV Supply Equipment (including charging stations and ancillary components) in-line with the regulatory standards that govern your product. Now you have a responsibility, in some cases mandatory, to have your product tested and certified ("listed") by an independent body recognized for their competency in electrical or mechanical safety. This allows you to sell your products in North America, and allows installers, retailers and inspectors to feel comfortable about your product's compliance to industry accepted safety standards. In the case of EV charging systems, Article 625 of the US National Electric Code (NEC) indicates that "all electrical materials, devices, fittings and associated equipment shall be listed or labeled", specifically Paragraph 625.1 Scope – The provisions of this article cover the electrical conductors and equipment external to an electric vehicle that connect an electric vehicle to a supply of electricity by conductive or inductive means, and the installation of equipment and devices related to electric vehicle charging. Ultimately the local AHJs – "Authority Having Jurisdiction" (often electrical code inspectors) have the final say in the acceptance of equipment and electrical installations. And the NEC tells the AHJ that one way of knowing a piece of equipment is okay, is to look for the "listing mark" of an approved lab.

4:00 **Extremely Sensitive Metallic Contaminant Detection System for Li-Ion Batteries**

Saburo Tanaka, PhD, Professor, National University Corporation, Toyohashi University of Technology, Japan

We have developed the magnetic metallic contaminant detectors using multiple superconducting ultra-sensitive magnetic sensor SQUID for lithium ion batteries. The quality of lithium ion batteries can be deteriorated by the inclusion of tiny metallic contaminants. Outer dimension of metallic particles less than 50 micron in motion cannot be detected by a conventional X-ray imaging. We successfully realized the inspection system for a continuous sheet electrode or separator of a lithium ion battery with width of at least 70 mm. Small iron particles of less than 50 micron were successfully measured.

4:30 **Exhibitors and Sponsors Showcase Presentations**

5:00 **Selected Oral Poster Highlights and Open Discussion & Concluding Remarks**

5:30 *Concluding Remarks, End of Conference*

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