1. Introduction
2. Battery Safety
3. Battery Trends
4. New Safety Solutions
Dr John Warner
Founder/President, Warner Energy Consulting

**Battery Industry**
- >10 years
- American Battery Solutions, Chief Customer Officer
- Ener1 / EnerDel / EnerTech, XALT Energy, Magna eCar, Boston-Power
- Executive leadership, Sales, Business Development, Product Management
- Technical advisor

**Automotive Industry**
- ~20 Years
- General Motors & GM Powertrain
- Program Management, Planning & Strategy
- Product and Mechanical Designer

**Standard & Trade Groups**
- NAATBatt International
  - 2018 President
  - 2017 President-Elect
  - Chair – Education Committee

- SAE International
  - Chair, Battery Size Standardization
  - Co-Chair, Advanced Batteries
  - Co-Chair, Bus Battery Safety
  - Member, Battery Testing Standards
<table>
<thead>
<tr>
<th>Component production</th>
<th>Cell production</th>
<th>Module production</th>
<th>Pack assembly</th>
<th>Vehicle integration</th>
<th>Use</th>
<th>Reuse and recycling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manufacture of anode and cathode active materials, binder, electrolyte, and separator</td>
<td>Production and assembly of single cells</td>
<td>Configuration of cells into larger modules that include some electronic management</td>
<td>Installation of modules together with systems that manage power, charging, and temperature</td>
<td>Integration of the battery pack into the vehicle structure, including the battery-car interface (connectors, plugs, mounts)</td>
<td>Use during specified in-vehicle battery lifetime</td>
<td>Battery reuse; deconstruction and cleaning preparatory to recycling of materials and components</td>
</tr>
</tbody>
</table>
New book out in April!!

Available now!

Available April 2019

www.Elsevier.com
Agenda

1. Introduction
2. Battery Safety
3. Battery Trends
4. New Safety Solutions
Top Energy Storage Priorities

Safety, Safety, Safety
Performance
Life
Cost
Lithium-ion Safety – Still Requires a Systems Solution

- Lithium-ion cell safety has improved significantly in the past 10 years
- But there is still no inherently “safe” cell
  - All chemistries can be driven to failure
- Lithium-ion and ESS safety must be managed using an integrated systems solution

There is No Silver Bullet!
Major Causes of Lithium-ion Battery Failures

Virtually all types of lithium-ion failures end in one of these three events:

- Short Circuit
- Gassing
- Impedance
Causes of Cell Failure

- **Short Circuit**
  - Internal Short
  - External Short

- **Gassing**
  - Dissolution of Active Material

- **Impedance Growth**
  - Lithium Plating
  - SEI Thickness Increase

**Non-Catastrophic Failures**
- Debris introduced during manufacturing
  - Dendrite growth
- Separator shrinking at high temperature
  - External force
- High temperature
  - Overcharge
  - Over Discharge

**Catastrophic Failures**
- Overcharge
- Over Discharge
- Cell aging
  - High rate charge/discharge
  - Low temperature
  - Improper formation cycle
  - Low temperature
- Foreign material connects across tabs
  - Penetration
  - Crush
- External force
- Short to housing
- High temperature
- Overcharge
- Over Discharge

Agenda

1. Introduction
2. Battery Safety
3. Battery Trends
4. New Safety Solutions
Trends in Lithium-ion Cells – Going Larger

Chevy Volt – 31Ah
Chevy Bolt – 63Ah

Lithium-ion cells are growing in capacity – future cells will reach nearly 300Ah
Battery Module Safety Systems

Monitoring and Balancing Electronics

Thermal Interface Gap Pads

Thermally Conductive Sheets

Plastic cell housings

Aluminum module case

Modules using Thermal Insulating Materials (TIM) to limit exposure to adjacent cells
Battery Pack Safety Systems

Packs using improved mechanical structures, thermal management system and Battery Management Systems.
Agenda

1. Introduction
2. Battery Safety
3. Battery Trends
4. New Safety Solutions
New and innovative safety solutions are being developed every day.
**Soteria Innovation Group: An Architecture of Safety**

**SEPARATOR FAILURE: FIRE**

- Separator retreats from short
- Conductor delivers energy

**Fuse Stops Ignition: No Fire**

- Conductor retreats from short
- No separator shrinkage

Separator never melts or shrinks
Metal layers fail like a fuse
Superior Safety from Patented Components

CURRENT COLLECTORS

Metallized film—similar to potato chip bag
- Thickness: ~4-6 μm, compared to 10-15 μm
- Weight: 15-25 g/m², compared to 45-90 g/m²
- Cost: 20% – 50% lower

<table>
<thead>
<tr>
<th>Thickness</th>
<th>Soteria Cu</th>
<th>15μm Al</th>
<th>Soteria Al</th>
</tr>
</thead>
<tbody>
<tr>
<td>10μm Cu</td>
<td>10μm</td>
<td>11μm</td>
<td>11μm</td>
</tr>
<tr>
<td>Metal Thickness</td>
<td>10μm</td>
<td>0.7 μm per side</td>
<td>15μm</td>
</tr>
<tr>
<td>Weight</td>
<td>90 g/m²</td>
<td>26.3 g/m²</td>
<td>43 g/m²</td>
</tr>
</tbody>
</table>

SEPARATORS

Nanofiber nonwoven—very fine paper
- Thermal stability: >300 C, compared to 120 C
- Cost: ~10% – 30% lower
- Produced on existing paper lines
NASA Full-scale safety validation

18650 cell with nail entry hole

High resolution CT scan of nail entry area. Light grey is cathode with Al Soteria films; dark grey is anode with Cu Soteria films.

Close-up of nail penetration area.

Light cathode layers have retreated below grey anode, preventing short through nail.

Open “alligator jaws” show residual electrode after collector retreated.

Cell with nail-hole is still working.
Dukosi Revolutionizes the Battery Pack

Dukosi Benefits:

• Eliminates wiring and connectors
• Reduces weight and volumetric need
• Real time SOC, SOH calculation and data storage at the cell – permanently
• Simplifies design and testing
• Simpler and safer – Wires = Fires

Conventional pack with wired BMS & slave unit(s)
Dukosi AS IC embedded in a prismatic cell
Dukosi Interface Unit replaces slave units
Dukosi pack with wireless BMS

Dukosi Antenna

Dukosi ASIC
Dukosi Interface Unit replaces slave units

Dukosi pack with wireless BMS
The Dukosi Solution

“Next Generation” 20Ah module demonstrates Dukosi integrated cell monitoring technology, with wireless data transmission to single RF cable

- 95% of wires & module connectors removed
- Integrated cell monitoring, compression and thermal management
- Modular for any series/parallel configuration
- Enables simple, low voltage manufacture
- Isolated bus antenna and interface module
- Isolated CAN and serial interfaces

CONFIDENTIAL - © Dukosi Limited
Fisker Solid State Battery (SSB)

1) Safety High-level
2) Overview
Solid State Batteries offer unique safety benefits versus Li-Ion

- No Liquid Electrolyte = Will not sustain combustion
  - Benign reaction to typical abuse cases e.g. overcharging and puncture
- Fundamentally safe chemistry e.g. no electrolyte breakdown resulting in cell failure
- Greater stability at elevated temperatures
- Improved manufacturing safety and reduced environmental impact
- Mitigates problems associated with dendrites
  - Reduced opportunity for internal short
  - Prevents thermal runaway associated with shorting found in current Li-Ion

References:
FISKER SOLID STATE BATTERY UNIQUE TECHNOLOGY

Energy Density = Range

<table>
<thead>
<tr>
<th>Traditional Li-Ion</th>
<th>Fisker SSB</th>
</tr>
</thead>
<tbody>
<tr>
<td>35% Active</td>
<td>&gt;80% Active</td>
</tr>
</tbody>
</table>

Ionic Mobility Impacts Power Density & Charging Time

<table>
<thead>
<tr>
<th>Traditional Li-Ion</th>
<th>Fisker SSB</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Internal Resistance (Tortuous Path)</td>
<td>Low Internal Resistance (Direct Path)</td>
</tr>
</tbody>
</table>

- 3D Bulk Electrodes Microstructure (>75µm)
- Increase in active surface area (power)
- Simplified Manufacturing (e.g. water based slurries)
- Uniaxially Oriented Pores
- Low internal resistance (low heat generation)
- Direct current path
Other cell and chemistry changes improving safety

- Aqueous Electrolytes
  - Non-flammable solvents
- Separators
- Metal films
- Materials
- Electrolyte Additives

- Solid-State Batteries
  - No liquid electrolytes
- Non-Lithium Chemistries
  - Na-ion
  - Mg-ion
  - Mn-ion
  - Air batteries
Many other Chemistry Options in Stationary Systems

- Other Chemistries
  - Nickel Zinc
  - Nickel Iron
  - Zinc

- Air Batteries
  - Zinc
  - Nickel

- Flow Batteries
Other emerging technologies may impact energy storage

- Blockchain
- Autonomous Vehicles
- Ride Sharing
- Behind the Meter home energy storage

New use cases will require new safety solutions
What is the Cost of Safety?

- Life
  - In 2017, 3,400 civilians died in fires.
  - Of these, 2,630, or 77% of all fire deaths, occurred in the home.
  - Another 400 civilians died in highway vehicle fires, which represents 12% of all fire deaths.
  - Nationwide, a civilian died in a fire every 2 hours and 34 minutes, and a civilian died in a home fire every 3 hours and 20 minutes.

- Financial
  - An estimated $23 billion in property damage occurred as a result of fire in 2017.
  - $10.7 billion in property damage occurred in structure fires, including $7.7 billion in property loss in home fires.
  - Highway vehicle fires resulted in $1.45 billion in property loss last year.
Large, Stationary Energy Storage Systems Have Unique Safety Requirements

- More energy
  - Stationary systems may range from small household systems up to multi-Megawatt-hour installations
- High voltages
  - Automotive limited to <400V
  - Truck and Bus limited to <800V
  - Stationary may be >1,000V
- Challenging environments
- Remote locations with limited infrastructure
- Multiple operating modes/profiles
- Cyber security
In the end, Safety should always be the primary decision factor.
Wrap-Up

- Battery prioritization
  - Safety, Safety, Safety
  - Then Performance, Life and Cost...in that order
- Lithium-ion cells are getting larger – future cells will reach nearly 300Ah
  - Safety solutions will have to take these into account
- Innovations happening at the materials, cell, chemistry and system levels that will improve safety, but safety still requires a System based solution
- Other chemistries emerging as players in the grid and stationary market

There is No Silver Bullet!