ZERO EMISSION BUSES AND FIRE MITIGATION

PRESENTED BY:
CHAD ROUSE

ALTERNATE FUEL VEHICLES

Currently there are two main categories of alternate fuel vehicles:

- Fully Electric
- Hydrogen Powered
  - Fuel cells
  - Hydrogen combustion engines

ELECTRICAL VEHICLE MYTH

Lithium batteries is the only major fire risk on an electric vehicle and since there is currently no detection and/or suppression solution for Lithium battery fires then there is no need for fire detection and suppression on EV buses.

While there are differences in the fire hazards of traditional fuel vehicles and alternate fuel vehicles, there are many similarities as well.

The approach to assessing the hazards and stopping a fire by breaking the fire triangle remains the same.

ELECTRIC VEHICLES

Hazards on Electric Vehicles

Potential ignitions sources:

- Battery Packs
- AC/DC Invertors
- Electric Drive Motors
- Compressors
- Auxiliary Heater
- High Voltage Cabling/Connections
- Wheel bearings & Brake issues

Potential fuel sources:

- Hydraulics
- Lubricants
- Coolants
- Fuels
- Plastics
- Batteries
- Hydrogen
- Tires

Many of the hazards on alternate fuel vehicles are the same as those of traditional vehicles

The major fire hazard difference is the present, size and quantity of Lithium Battery Packs

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ELECTRIC VEHICLES

Additional factors to consider when assessing the hazards of Electric vehicles:

In addition to looking at potential ignition sources and fuel sources and where they are relative to one another, where these components are relative to where Lithium battery packs are located should also be considered.

The current tendency is for bus manufacturers to locate battery packs all over the vehicle is any available space. The makes fire detection and suppression solutions much more complicated.

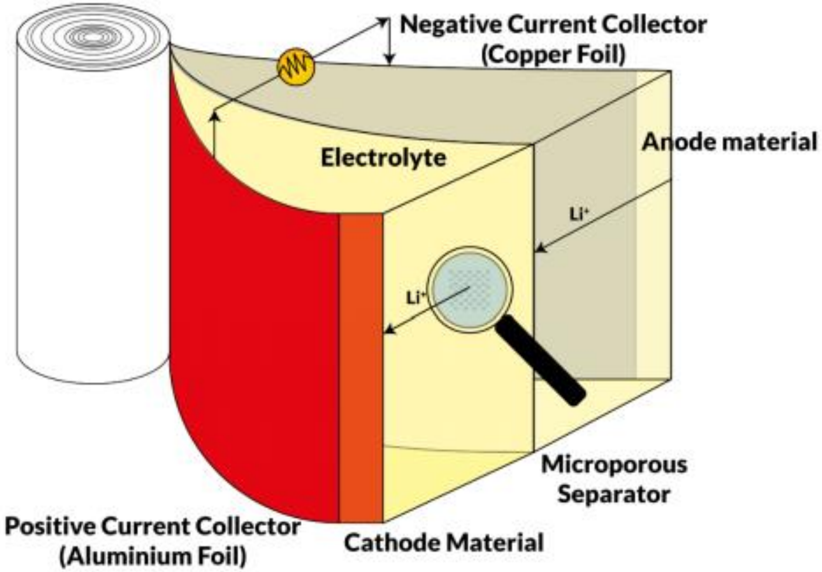
Battery pack casing materials. Are casing materials such that they assist in the preventing propagation of a thermal event?

- Evolving battery pack case designs seem focused on weight reduction.

LITHIUM-ION BATTERIES

- Battery Types

- Primary
  - Non-rechargeable, “button cells”, used in watches, camera, hearing aids etc.
- Secondary
  - Re-chargeable used in a wide range of applications from consumer electronics, medical, cars to military / aviation
  - Anode is copper foil coated with carbon structure
  - Cathode is aluminum foil coated with metal oxide
  - Polyolefin separator
  - Electrolyte with dissolved Li salt (ethylene carbonate, diethyl carbonate) – typically flammable as are their thermal decomposition products
  - Li salt is commonly lithium hexafluophosphate (LiPF6) – produces HF during venting
  - Li ions move from anode to cathode during discharge and are captured into the cathode structure (voids)
  - “Jelly Roll” design common



LITHIUM-ION BATTERIES

- Cells, Modules, & Packs
- Cells come in cylindrical (AA, AAA, D), pouch and prismatic types
- Cell sizes
  - 18650 and 21700 are common sizes
  - 18mm diameter 65mm length etc.
  - Note new Tesla Cells are 4860 48mm dia. X 60mm length!
  - Significantly higher energy density & Power
- Place cells in parallel and/or series to achieve discharge capacity or voltage
  - E.g. eBike 10 cells in series → 36V
  - Then 4 modules to give required current
  - Typical Voltage for Bus = 600V+
- Can be further combined into packs that have monitoring circuitry for charging and discharging

Cells

Module

(9X8X2) ~ 144 Cells)

Packs

(8X2X144 ~ 2340 Cells)

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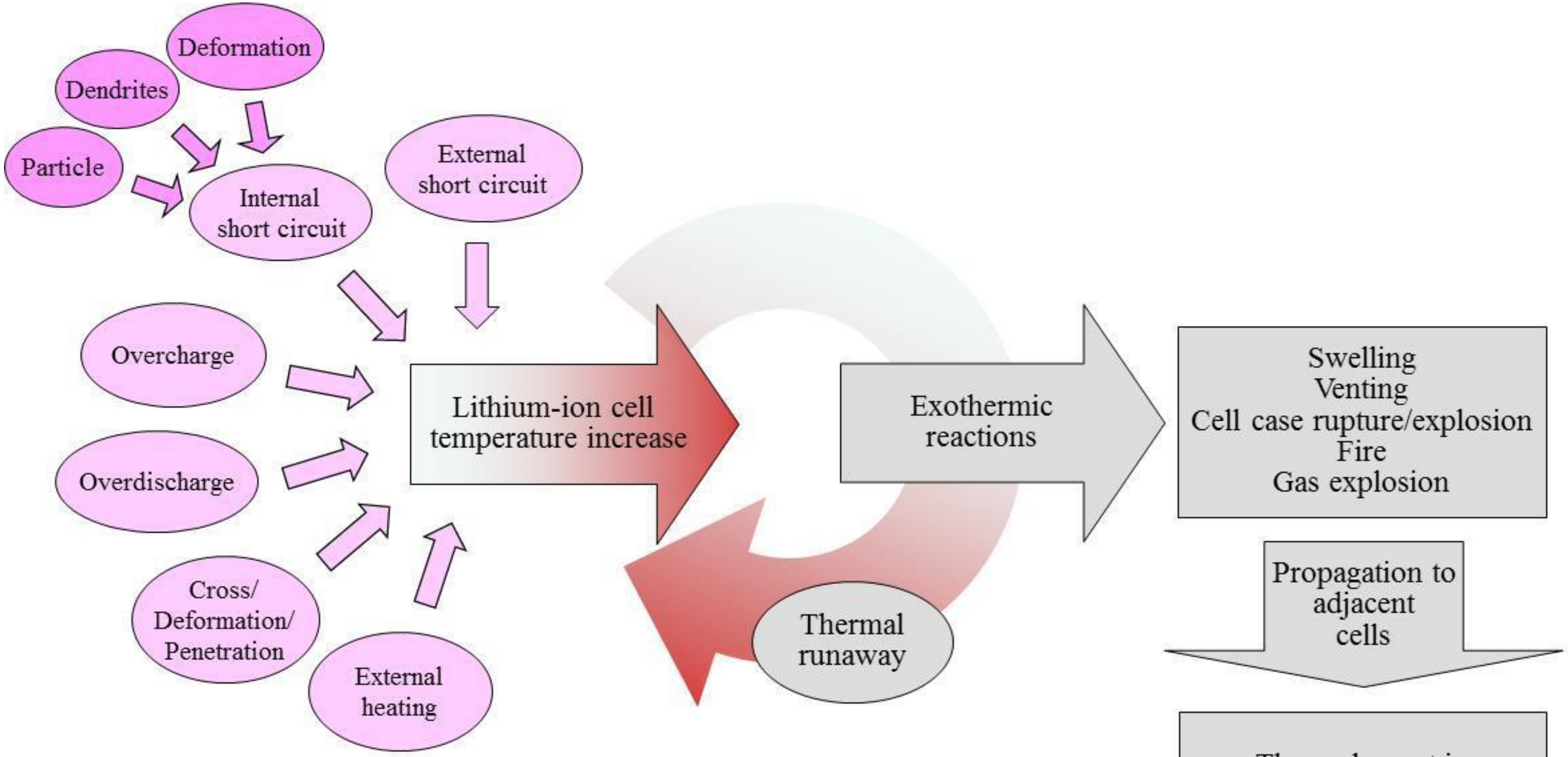
LITHIUM-ION BATTERIES

- Battery Chemistries

Abbreviation	Chemical Name	Chemical Forumula	Application
LCO	Lithium Cobalt Oxide	$LiCoO_2$ (60% Co)	High capacity for cell phones, cameras etc..
LMO	Lithium Manganese Oxide	$LiMn_2O_4$	e.g. Ford Focus (LMO,NMC blend)
LFP	Lithium Iron Phosphate	$LiFePO_4$	e.g. BYD (2010), Volvo 7900
NMC	Lithium Nickel Manganese Cobalt Oxide	$LiNiMnCoO_2$ (10-20% Co)	e.g. VW-E-Golf (2015), Honda Fit EV, Renault Zoe (2014)
NCA	Lithium Nickel Cobalt Aluminium Oxide	$LiNiCoAlO_2$ (9% Co)	e.g. Tesla (2012 - 2018)
LTO	Lithium Titanate	$Li_4Ti_5O_{12}$	e.g. Solaris Urbino, VDL Citea

LITHIUM-ION BATTERIES

- Failure Modes



Fires involving lithium batteries can initiate within the product, which means that in storage, a fire can initiate deep within a battery pack or piece of equipment, beyond the influence of conventional fire protection systems

LITHIUM-ION BATTERIES

Another Myth – " I have a battery management system therefore I do not need a fire system"

- Battery management systems perform important role in preventing some hazards
  - Failure rates 1 in 10,000,000 cells
  - >4 B made per year

Abuse Type	Battery Management Sytem Protection	Protection Strategy
Internal Cell Short Circuit	NO	
External Cell Short Circuit	POSSIBLE *	BMS can protect if short circuit is protected by a circuit breaker
External battery pack short circuit	YES	Disconnect Battery using a fuse or contactors
Overcharge	YES ***	Disconnect Battery using a fuse or contactors
Overdischarge	YES ***	Disconnect Battery using a fuse or contactors
External Heating, Mild	YES	Cooling using thermal management system
External Heating, Strong	NO	
External Fire	NO	
Mechanical cross / deformation / penetration	NO	

* This case refers to a situation with an external short circuit of one or multiple cells inside the battery pack. Theoretically, many short circuit paths are possible and if the short circuit happens to be within a current path involving a fuse or possible contractors then it is possible to stop the short circuit

** Spontaneously starting a micrometre scale inside the cell due to e.g. particle contamination or dendrite formation

*** The detection and the consequent actions until current shutdown must be rapid enough to ensure that the battery is not exposed to over/ under voltages.

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CURRENT KIDDE ELECTRIC VEHICLE STRATEGY

- CURRENT DETECTION AND SUPRESSION STRATEGY

Kidde recommends a two-pronged approach to fire detection and suppression on electric vehicles

- Targeting non-Lithium fire hazards on vehicle with the thought of preventing a thermal event from propagating to the Lithium batteries
- Targeting Lithium fire threats

CURRENT KIDDE ELECTRIC VEHICLE STRATEGY

- CURRENT DETECTION AND SUPRESSION STRATEGY

Targeting non-Lithium fire hazards on an Alternate fuel vehicle

- Areas where there are fire threats other than lithium batteries, the same detection solutions as used for Petrol vehicles should be utilized. The use of linear detection would be Kidde's minimum recommendation.
- The use of Optical detection is recommended in conjunction with linear detection in larger areas containing hazards such as invertors, auxiliary heaters, air and AC compressors can be monitored for flame to provide faster response and an alternate detection method to heat rise.
- The use of Purple K dry chemical agent is recommended due to its superior suppression performance, ease of clean up, its non-corrosiveness, and its environmentally friendliness

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CURRENT KIDDE ELECTRIC VEHICLE STRATEGY

- CURRENT DETECTION AND SUPRESSION STRATEGY

Targeting Lithium Fire Threats

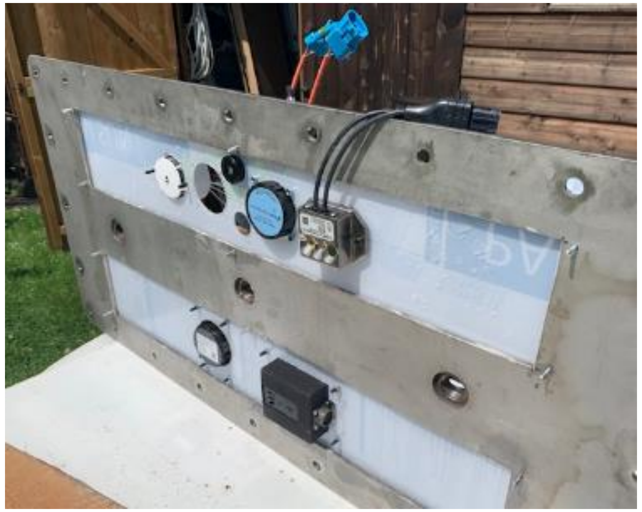
- Currently no known agent can keep a lithium fire from flaring back up after suppression.
- Kidde recommends detection inside of Lithium battery encasements. At a minimum, this type of monitoring can be used to provide an indicator to the vehicle operator.
- If Lithium battery modules are encased in a sealed metal box that cannot be penetrated, there is little gained by having detection and suppression targeting the outside of the metal encasement.
- If Lithium battery modules are encased in a box that is not solid metal, Kidde recommends detection and suppression in the encasement, but at a minimum Kidde recommends external detection and suppression targeting the battery encasements.

FUTURE KIDDE LITHIUM-ION BATTERY STRATEGY

Kidde is currently working to develop the Next Generation of Detection And Suppression solutions for Lithium Battery fires.

Kidde is testing various detection and suppression methods against fire challenges with LI batteries

<u>The key</u> is getting detection and suppression inside of battery packs to have a shot as preventing thermal runaway and suppressing a Lithium thermal event.



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DETECTING LITHIUM BATTERY THERMAL RUNAWAY

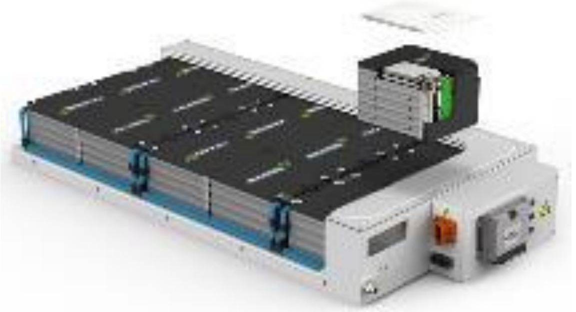
Normal Operation

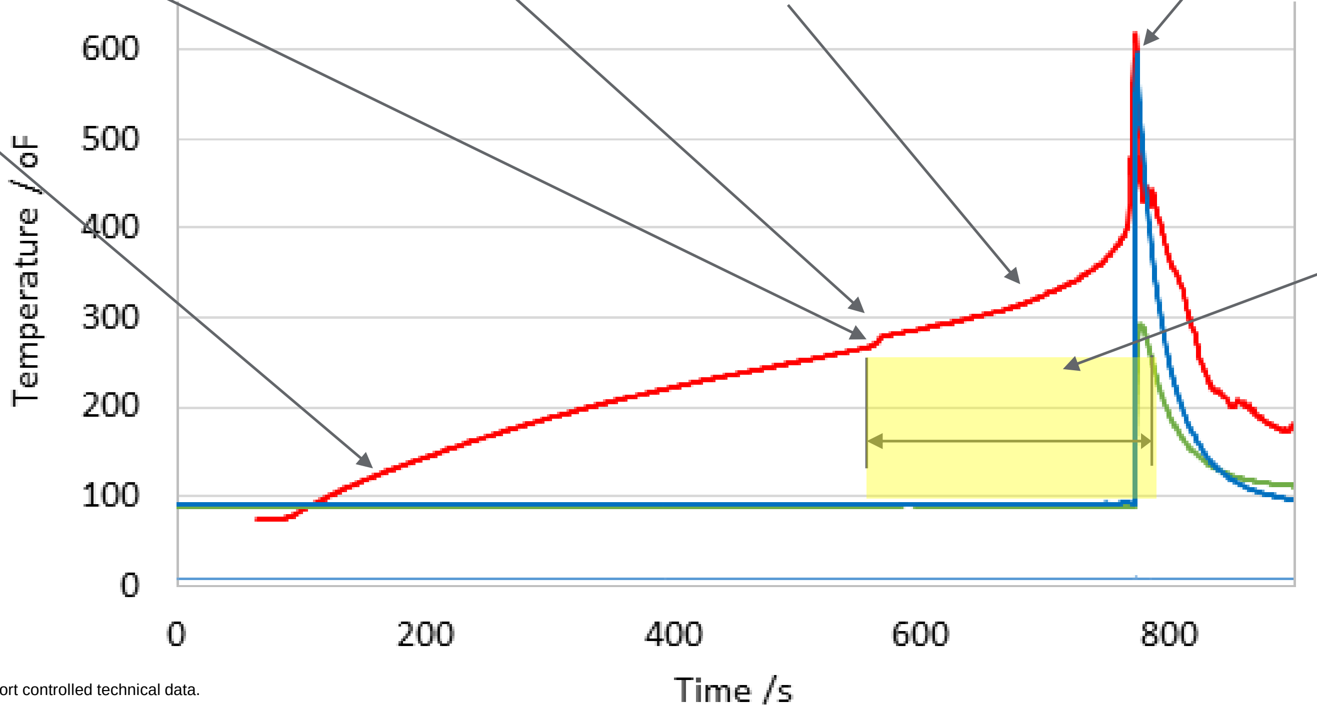
Vent

Slow Gas

Rapid Gas

Fire





Zone for Detection Opportunities

VIDEO OF BATTERY OVERHEAT

KIDDE FUTURE LITHIUM STRATEGY

Normal Operation

Battery Management System (BMS) and AFSS monitoring within the lithium packs to provide early detection of potential issues that could result in a cell failure and provide notification.

Level 1

Cell vent/rupture – AFSS early detection detects cell venting and is used to turn off charging or remove load from pack upon alarm. Stop the vehicle and evacuate. Call fire department.

Level 2

Thermal runaway – Rapid detection and deploy of suppression agent into zone(s) with active fire threat. Rapid application of agent can suppress the flame and reduce the chance of cell-to-cell thermal runaway.

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KIDDE LITHIUM RESEARCH TAKEAWAYS

1. Early Detection after initial cell venting and isolation are key to mitigating thermal runaway and propagation to surrounding cells
   - To achieve this detection and suppression must occur inside the battery packs.

2. Once thermal runaway occurs, the key is immediate suppression and cooling followed by sustained cooling.
   - Ports on battery packs that allow both inflow and outflow of agent
   - Piping system that allow fire responders continue flowing cooling agent thru battery packs

3. Fire systems may need to become more complicated and complex:
   - Directing agent to battery pack with thermal event.

4. Only by customers, bus manufacturers, battery manufacturers, and fire system companies working together will an effective detection and suppression solution for Lithium Packs be achieved.

QUESTIONS

Chad Rouse
Chief Sales Engineer
252-218-2225
Chad.rouse@collins.com

www.kiddetechnologies.com