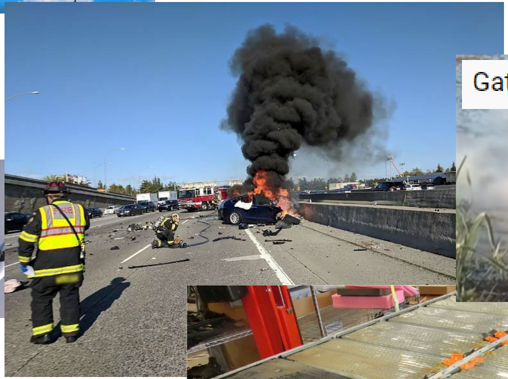
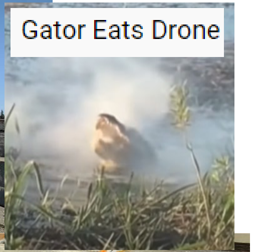
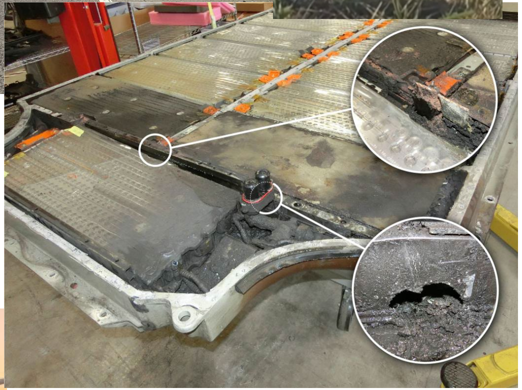






NASA Aerospace Battery Workshop

Emergency Response Plans: Needs for eAero Applications

November 2021

Brian Engle
xEV/ Battery Business Development Manager
brian.engle@amphenol-sensors.com
US: 248 978 5736
amphenol-sensors.com

E-Aero Growth

E-Aero Market – ***$115B AAM market by 2035. This is 30% of US commercial aerospace market and .05% of US GDP in 2019. Morgan Stanley estimates $1T by 2040, $12B by 2030, and ultimately a $9T Global Market***

- Joby – Begin operations 2024; Annual production 250 by 2025, 580K sqft manufacturing Marina Regional Airport California, partnered with Toyota, expanding to LA and San Diego as well as west coast. 2023 FAA certification and production facility online. $1.3M build cost per aircraft
- Lilium – Berlin, DE, Vertiport build Orlando, 20M customer access
- Archer – Building vertiport in Miami, 17M customer access, United airline deal for $1B + $500M option
- Volocopter – Raises €200M Series D, DOA from EASA, targets Singapore for 2024 operations, 2022 certification
- Wisk – Partnered with Japan airlines, New Zealand FAA approved transportation
- Ehang – Estimates taxi service in Dubai by 2022, IPO Dec 12, 2019, Partner is Vodaphone
- Bye Aerospace – 1,305 aircraft by 2029, 10-year life span for aircraft
- Hyundai pledges $1.5B investment to AAM
- 50 Cities globally considering Air Mobility
- Dallas, Los Angeles, and Melbourne committed to AAM
- Auto Manufacturers – GM, Toyota, Audi, Porsche, Fiat Chrysler, Hyundai, Aston Martin, Geely
- Estimated 430,000 global units by 2040

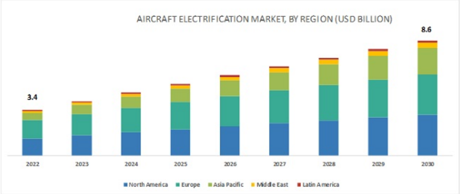
Drone Market – ***The global Commercial Drones market size is expected to gain market growth in the forecast period of 2020 to 2025, with a CAGR of 24.3% in the forecast period of 2020 to 2025 and will expected to reach 5179.4 million by 2025, from 2167.8 million in 2019.***

Beta Technologies announces deal with UPS for up to 150 eVTOL aircraft

United Airlines Pre-Orders $1 Billion of Electric Planes Made By Archer Aviation

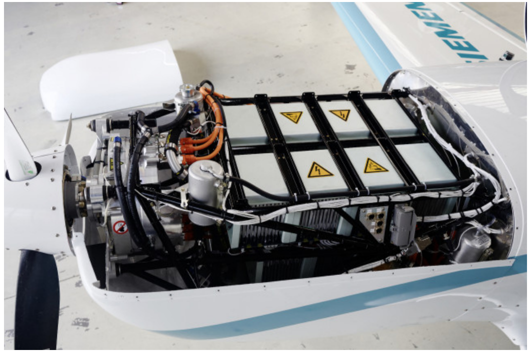
Market growth driven by need for net zero transportation

- Supported by availability of Li-ion batteries
- Most will use existing Li-ion battery chemistries and package designs
- Leveraging surface vehicle supply base and infrastructure
- High energy, fast charging and battery swapping to reduce downtime



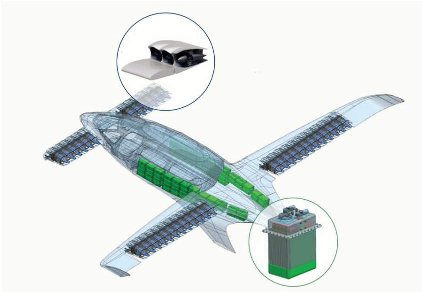
Market moving from pilot stage to launch before 2024

From laboratory to the field….



This week's NASA Workshop has shown excellent work:

- Improved simulation of battery behavior and failure
- Test and Validation methods
- New & Improved analysis techniques
- TR Mitigation tools and techniques
- Improvements in battery design and chemistries



eAero - New applications and challenges for TR and First Responders:

- Drones and e-Aero applications will use non traditional flight corridors with much greater geographic exposure
- Only Airport First responders currently provided unique aircraft specific training
- First Responders have issues with fighting battery events today
- Current tools and approach may need to change

The Challenge:

- Many of these eAero and drone applications are in development now, using existing tools and hardware
- It is likely that while infrequent, incidents of Thermal Runaway in drones and e-Aero will occur

How do we improve the outcome over surface vehicles and ESS failures?

CURRENT TOOLS: EMERGENCY RESPONSE GUIDES

ISO 17840-3:2019

Road vehicles — Information for first and second responders — Part 3: Emergency response guide template

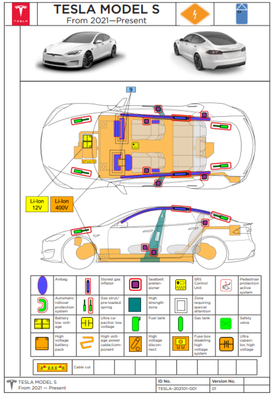
The ERG template provides a format for filling in the following necessary and useful emergency information:

— relevant information for a vehicle involved in a traffic accident (including immobilisation, disabling of hazards, access to occupants, shut-off procedures, handling of stored propulsion energy);
— information in case of fire or submersion; and
— information regarding towing, transportation and storage.

This document is applicable to passenger cars, buses, coaches, light and heavy commercial vehicles according to ISO 3833.
The proposed template can be beneficial for use also for other types of vehicles (e.g. trains, trams, airplanes), although this is out of the scope of this document.

- Uses standard documentation and "EuroRescue" smartphone app to access database
- Enforced by EuroNCAP vehicle ratings

Should same/similar model be used for drones and eAero apps?



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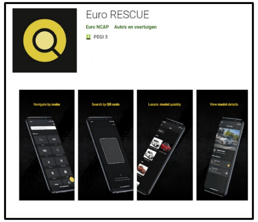
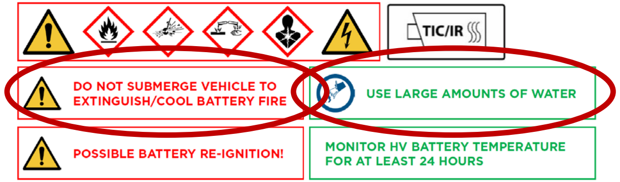




USE WATER TO FIGHT A HIGH VOLTAGE BATTERY FIRE. If the battery catches fire, is exposed to high heat, or is generating heat or gases, use large amounts of water to cool the battery. It can take between approximately 3,000-8,000 gallons (11,356-30,283 liters) of water, applied directly to the battery, to fully extinguish and cool down a battery fire; always establish or request additional water supply early. If water is not immediately available, use CO2, dry chemicals, or another typical fire-extinguishing agent to fight the fire until water is available.

NOTE: Tesla does not recommend the use of foam on electric vehicles.

First Responder Training Issues

Andrew Klock, NFPA / Kurt Vollmacher EU

- **In US, 300k trained; >800k need training**
- **Over 300k in EU still need training**

With the increasing prevalence of electric (EV) and hybrid vehicles all over the world, it is important for the first and second responder communities to be educated on the various unique safety risk these vehicles may present. Since 2010, the National Fire Protection Association's (NFPA) Alternative Fuel Vehicle Safety Training Program has teamed up with major auto manufactures, subject matter experts, fire, law enforcement and safety organizations in order to address these safety needs. Through our years of research and work in this field we have developed a comprehensive curriculum for first responders when dealing with alternatively fueled vehicles which include instructor led classroom courses, free interactive online learning, an Emergency Field Guide, and informational/educational videos.

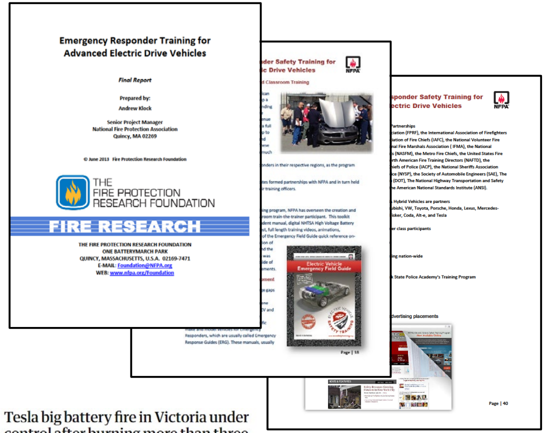
Here are a few important takeaways on EV and hybrid fire safety for first responders:

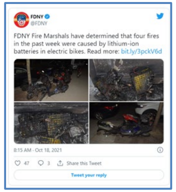
1. When suppressing a vehicle fire involving an EV or hybrid, water is the recommended extinguishment agent. Large amounts of water may be required, so be sure to establish a sufficient water supply before operations commence.
2. As with all vehicle fires, toxic byproducts will be given off, so NFPA compliant firefighting PPE and SCBA should be utilized at all times.
3. ***DO NOT attempt to pierce the engine or battery compartment of the vehicle to allow water permeation, as you could accidentally penetrate high voltage components.***
4. Following extinguishment, use a thermal imaging camera to determine the temperature fluctuation of the high voltage battery before terminating the incident, to reduce re-ignition potential

Legacy philosophy of some manufacturers was to "Let it Burn" when dealing with damaged cells and thermal runaway; and this is challenged by First Responders

Inconsistent recommendations create confusion and increase risk

NYC e-bike infernos: Scooter, e-bike batteries caused 55 fires, two deaths so far this year, FDNY says





Tesla big battery fire in Victoria under control after burning more than three days

Investigations into the cause of the blaze that began during testing on Friday can now begin

Get our free news app and our morning email briefing

"They are difficult to fight *because you can't put water on the mega packs* … all that does is extend the length of time that the fire burns for."
Firefighters have taken advice from experts including Tesla, the battery's creators, and UGL, who are installing the battery packs.
"The recommended process is you cool everything around it so the fire can't spread and *you let it burn out*," Beswicke said.

25 May 2021

Accident analysis of the Beijing lithium battery explosion which killed two firefighters

Electrical accidents at work, Hazmat, Industrial Fire, Lessons Learned, Line of Duty Deaths, Lithium battery explosions, Lithium battery fires

On April 16 an explosion occurred when Beijing firefighters were responding to a fire in a 25 MWh lithium-iron phosphate battery connected to a rooftop solar panel installation. Two firefighters were killed and one injured. CTIF can

Amphenol

Surface vehicle standard practice to supress fire and relieve stranded energy

Response vehicles typically only have ~500 to 1500 gallons of water available on board

Current
“Water Immersion”
& “Large amounts of water”

New Development:
AVL Water “spike” into pack substantially reduced water usage

New field Tools for First Responders:
“Spike” systems from Murer, Rosenbauer

First Application Example

- Renault Zoe Q210
  - Nominal power: 46 kW
  - Max. power: 65 kW
  - Battery capacity: 22kWh
  - Pouch Zellen
- Battery ignited by penetration
- Max temperature after penetration: >600°C
- Water consumption: approx. 300l
- Extinguishing time: 20min
  ->15l/min water
- Temperature after extinguishing: <90°C
- After extinguishing the vehicle was transferred in a container with water

Press release

rosenbauer

October 7, 2021

New extinguishing system for burning traction batteries in electric vehicles

- Safe deployment due to short deployment time on the burning vehicle and system activation with sufficient distance
- Efficient firefighting by cooling the modules and cells in the battery housing
- Lead users confirm the efficiency and ergonomics of the system

Rosenbauer launches a new extinguishing system for burning traction batteries in electric vehicles. The system can be used to safely and efficiently extinguish lithium-ion based high-voltage batteries. It enables direct cooling of the battery modules, or the cells within the modules, and thus a quick stop to the propagation of the thermal runaway of the cells.

The safety of the firefighter was the top priority during the development and is achieved by the fact that the firefighter only being in the vicinity of the burning vehicle for a very short time and the system is activated from a safe distance. The extinguishing system applies the water exactly where it is needed: to cool the cells and modules in the battery housing. Extinguishing thus takes place in a very resource-efficient way and reduces the spread of flue gases to a minimum.

5,000 to 30,000 gallons → **80 gallons**

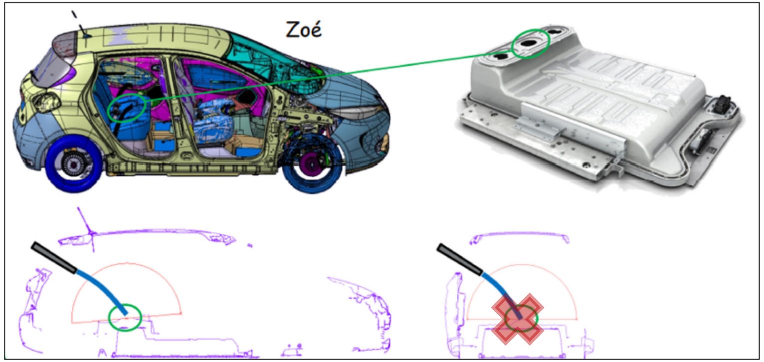
- Water immersion may work for small drones, not an option for eVTOLs / e Aircraft
- “Spike systems” need identified locations for piercing to avoid striking HV bussing & cables

Standard, uniform procedures are needed for e Aircraft
Stranded Energy and second Responder safety need to be addressed

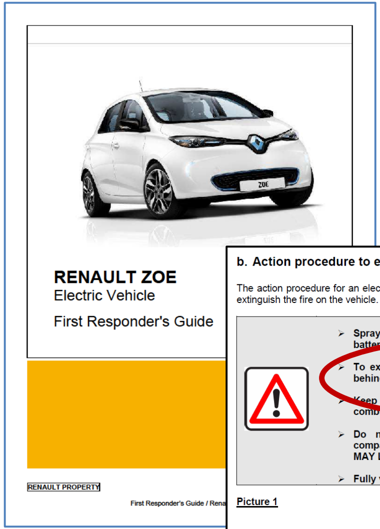
Renault Zoe example; AMOST got it right

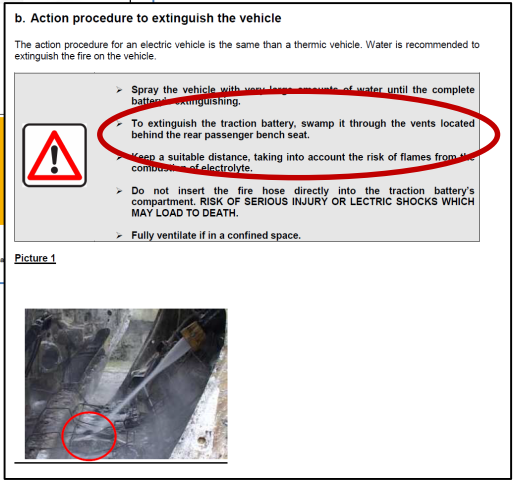
“Fire Hose Access” allows for direct battery immersion
Information on design is in Emergency Response Guide

Renault has developed a system whereby water can be introduced into the battery pack from the outside.
This is done by means of a thermal plate, which is mounted on top of the battery house and melts away in case of fire.
in case of fire and thus gives access to the high-voltage battery.



- Occupants exposed to hazardous/flammable gases!





b. Action procedure to extinguish the vehicle

The action procedure for an electric vehicle is the same than a thermic vehicle. Water is recommended to extinguish the fire on the vehicle.

- Spray the vehicle with very large amounts of water until the complete battery's extinguishing.
- To extinguish the traction battery, swamp it through the vents located behind the rear passenger bench seat.
- Keep a suitable distance, taking into account the risk of flames from the combustion of electrolyte.
- Do not insert the fire hose directly into the traction battery's compartment. RISK OF SERIOUS INJURY OR LECTRIC SHOCKS WHICH MAY LOAD TO DEATH.
- Fully ventilate if in a confined space.

Picture 1

Impact of Cascading TR on aircraft function and structure must be considered

Safety of Occupants, First/Second Responders and nearby personnel must be considered in e-Aero applications

First & Second Responders Survey 2021

"First" survey on EV response of its kind

Survey issued in 2020/21: >500 respondents, ~30% experienced xEV incidents

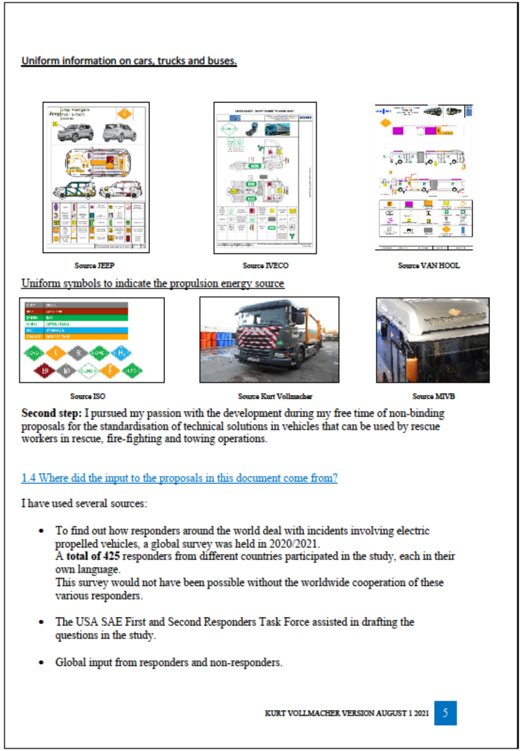
Kurt Vollmacher, ISO17840 Author

<u>Key Findings & Needs:</u>

- Additional training needed in all regions
- Need for clear recognition of xEV's

    Belgium: proposed ISO icon on plate; Germany "E" at end of plate

- Uniform, globally available information per ISO 17840
- Uniform disconnect system design and placement
- Uniform procedures for extrication and firefighting
- System to make it easy to extinguish HV batteries
- Safety systems to deal with HV stranded Energy
- Handling of xEV's in car parks



Uniform information on cars, trucks and buses.

Source JEEP Source IVECO Source VAN HOOL

Uniform symbols to indicate the propulsion energy source

Source ISO Source Kurt Vollmacher Source MIVB

Second step: I pursued my passion with the development during my free time of non-binding proposals for the standardisation of technical solutions in vehicles that can be used by rescue workers in rescue, fire-fighting and towing operations.

1.4 Where did the input to the proposals in this document come from?

I have used several sources:

- To find out how responders around the world deal with incidents involving electric propelled vehicles, a global survey was held in 2020/2021.
  A **total of 425** responders from different countries participated in the study, each in their own language.
  This survey would not have been possible without the worldwide cooperation of these various responders.
- The USA SAE First and Second Responders Task Force assisted in drafting the questions in the study.
- Global input from responders and non-responders.

KURT VOLLMACHER VERSION AUGUST 1 2021 5

What will be the equivalent of EuroRescue and ISO 17840 for eAero Applications?

Surface vehicle concerns: NTSB Report – Jan 2021 (T. Barth)

Safety Issues:

• Inadequacy of emergency response guides for minimizing risks to first and secondary responders from Li-ion battery fires

• Gaps in safety standards for high-speed, high-severity crashes involving Li-ion battery vehicles

Recommendations:

NHTSA:

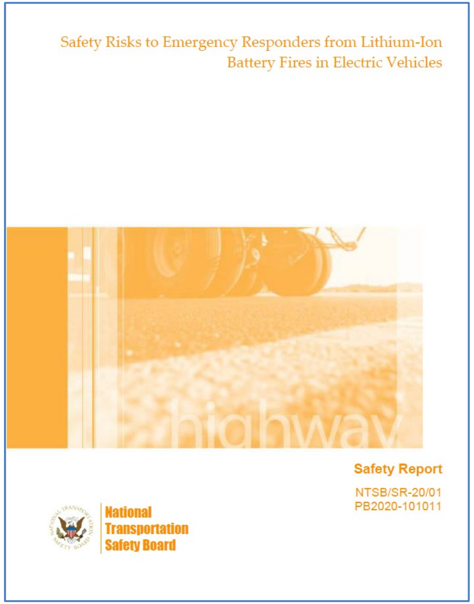
• Incorporate Emergency Response Guides (ERGs) into NCAP
• Continue research on mitigating or de-energizing stranded Energy

EV Manufacturers (cars, trucks, buses in USA)

• Model ERGs on ISO 17840 and SAE J2990
• Vehicle specific information on fire fighting, stranded energy, safe storage

Responder Associations (NFPA, IAFC, IAFF, AFTC, NVFC, TRAA)

• Inform members of risks and available guidance



https://youtu.be/J6eS6JzBn0k

Need for identifying stranded energy and denergizing damaged cells

Need quantifiable metrics for containment – How do we know when the event is finished?

State of the Industry for Thermal Propagation countermeasures

- **On vehicle:**
  - "Livestream" venting/battery data to secure server
  - Aggressive HX
    - Coolant
    - refrigerant
  - Load dump from affected modules (as with MegaPack)
  - Phase change materials that absorb heat
  - Disable regen braking contribution to pack charging
  - Disable charging
  - Thermal isolation
  - On board extinguishing agents (busses)
  - Dielectric coolant
  - Access port

- **Off vehicle**:
  - ISO bath (ISO 17840 / SAE J2990)
  - E lance
  - Lots of water
  - See First Responder Survey Recommendations

VW ID.3 Suppression

Gator Eats Drone

https://youtu.be/JBHStR_SuPc

Summary: Emerging Needs for eAero Emergency Response

Research needs:

- Potential for HV discharge with cell venting gases and ejecta
- Oxygen inventory within battery modules and potential for flash fires with venting
- Technique to easily Identify stranded energy

Procedures / Standards:

- Qualification test standards for TR protection during qualification: preventing occupant exposure to hazardous & flammable gas
- System level techniques to prevent TR propagation / prevent critical aircraft damage

New First Responders Tools needed:

- Standard Document for Emergency Response Guides
- “EuroRescue” style accessible database
- Training for First Responders
- Tools to detect presence of flammable & hazardous gases within enclosure spaces
- Tools that can identify stranded energy in damaged packs
- Safe discharge method for stranded energy/damaged cells
- Tools to quench TR event on e Aircraft packs

NASA Aerospace Battery Workshop

Emergency Response Plans: Needs for eAero Applications

November 2021

Brian Engle
xEV/ Battery Business Development Manager
brian.engle@amphenol-sensors.com
US: 248 978 5736
amphenol-sensors.com

Background: SAE Battery Standard Steering Committee

September 2, 2020

Robert L. Galyen

BATTERY STANDARDS STEERING COMMITTEE

- Started – 2009
- Committee Membership
  - >290 Individual Participants
  - >160 Companies
    - OEM's
    - Suppliers
    - Government
    - Academia
- 23 Subcommittees

NEW COMMITTEES

- 24) Electric Vehicle Battery Service
- 20) International Battery Interface

COMPONENTS & MATERIALS

- 23) Battery Systems Adhesives-Sealants-Heat Transfer Materials
- 21) Battery Thermal Management
- 19) Battery Systems Connectors
- 14) Battery Materials Testing

SUPPORT

- 4) Battery Transport
- 12) Battery Testing Equipment
- 13) Battery Terminology
- 3) Battery Labeling

LIFE MANAGEMENT

- 10) Battery Recycling
- 18) Battery Field Discharge & Disconnect
- 15) Secondary Use

PRODUCT SPECIFIC

- 2) Battery Standards Testing
- 1) Battery Safety
- 16) Start-Stop Battery
- 17) Capacitive Energy Storage
- 9) Battery Standards Future Energy Storage Systems
- 5) Battery Size Standardization
- 6) Starter Battery
- 8) Battery Standards Electronic Fuel Gauge

INDUSTRY SPECIFIC

- 11) Small Task Oriented Vehicle Batteries
- 7) Truck Batteries
- 22) Bus Battery

BATTERY STANDARDS COMMITTEE DOCUMENTS

10 Active
15 Under Revision
2 Stabilized
7 New in Progress

Battery Life Assessment Testing: J240, J2185, J2288, J2801

Sealing, Adhesives, Thermal Management: J3073, JXXXX

Battery Testing Methodologies: J537, J1495, J2758 , J930

Future Battery Systems: JXXXX

Battery Materials Testing: J2983, J3021, J3042, J3159

Functional Guidelines: J2289

Vibration: J2380, J3060

Battery Labeling: J2936

Battery Recycling: J3071, J2974, J2984

Battery Safety: J2929, J2464, J2946

Battery Transport: J2950

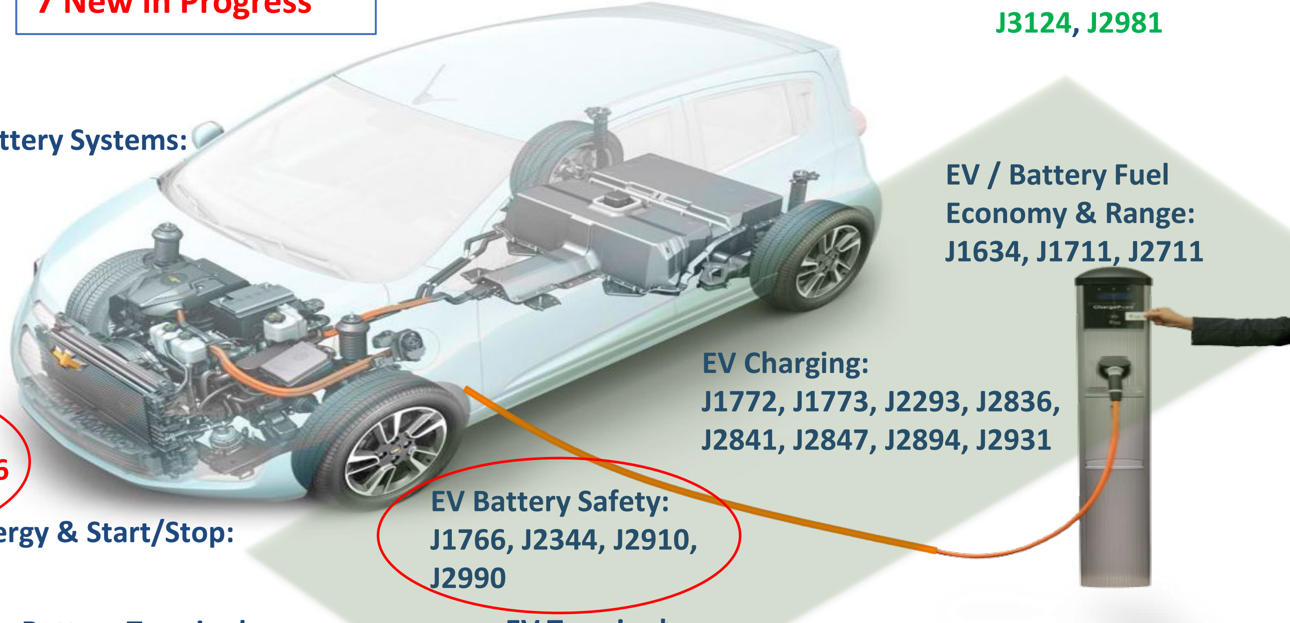
Capacitive Energy & Start/Stop: J3012, J3051

Battery Terminology: J1715/2

Battery Testing Equipment: JXXXX

Battery Performance Rating: J1798

Battery Size, Identification & Packaging: J1797, J3124, J2981



EV / Battery Fuel Economy & Range: J1634, J1711, J2711

EV Charging: J1772, J1773, J2293, J2836, J2841, J2847, J2894, J2931

EV Battery Safety: J1766, J2344, J2910, J2990

EV Terminology: J1715

Battery Safety Documents

J2990:Hybrid and EV First and Second Responder Recommended Practice

xEVs involved in incidents present unique hazards associated with the high voltage system (including the battery system). These hazards can be grouped into 3 categories: chemical, electrical, and thermal. The potential consequences can vary depending on the size, configuration and specific battery chemistry. Other incidents may arise from secondary events such as garage fires and floods. These types of incidents are also considered in the recommended practice (RP). This RP aims to describe the potential consequences associated with hazards from xEVs and suggest common procedures to help protect emergency responders, tow and/or recovery, storage, repair, and salvage personnel after an incident has occurred with an electrified vehicle. Industry design standards and tools were studied and where appropriate, suggested for responsible organizations to implement.

- **J2990/1:** Gaseous Hydrogen & Fuel Cell Vehicle First and Second Responder Recommended Practice
- **J2990/2:** Hybrid and Electric Vehicle Safety Systems Information Report

"This report describes some of the general safety systems and practices employed by OEMs to help assure the general public of the safety of these vehicles and to explain why test safety systems and practices do help protect against high voltage contact."

J2464: Electric and Hybrid Electric Vehicle Rechargeable Energy Storage System (RESS) Safety and Abuse Testing

This SAE Recommended Practice is intended as a guide toward standard practice and is subject to change to keep pace with experience and technical advances. It describes a body of tests which may be used as needed for abuse testing of electric or hybrid electric vehicle Rechargeable Energy Storage Systems (RESS) to determine the response of such electrical energy storage and control systems to conditions or events which are beyond their normal operating range.

Abuse test procedures in this document are intended to cover a broad range of vehicle applications as well as a broad range of electrical energy storage devices, including individual RESS cells (batteries or capacitors), modules and packs. This document applies to vehicles with RESS voltages above 60 volts. This document does not apply to RESS that uses mechanical devices store energy (e.g., electro-mechanical flywheels).

J2929: Electric and Hybrid Vehicle Propulsion Battery System Safety Standard - Lithium-based Rechargeable Cells J2929_20110

This SAE Standard defines a minimum set of acceptable safety criteria for a lithium-based rechargeable battery system to be considered for use in a vehicle propulsion application as an energy storage system connected to a high voltage power train. While the objective is a safe battery system when installed into a vehicle application, this Standard is primarily focused, wherever possible, on conditions which can be evaluated utilizing the battery system alone. As this is a minimum set of criteria, it is recognized that battery system and vehicle manufacturers may have additional requirements for cells, modules, packs and systems in order to assure a safe battery system for a given application. A battery system is a completely functional energy storage system consisting of the pack(s) and necessary ancillary subsystems for physical support and enclosure, thermal management, and electronic control

Battery Safety Documents

J2946: Battery Electronic Fuel Gauging Recommended Practices

This document covers the recommended practices associated with reporting the vehicle?s (hybrid and pure electric) battery pack performance details to the automobile user. Specifically, performance details refer to the amount of stored energy available for use by the vehicle?s hybrid or pure electric drive system. These practices detail the accuracies, error conditions and other reporting and diagnostic requirements responsible for delivering an accurate assessment of the amount of available electrochemical fuel.

J1766: Recommended Practice for Electric, Fuel Cell and Hybrid Electric Vehicle Crash Integrity Testing

Electric, Fuel Cell and Hybrid vehicles may contain many types of high voltage systems. Adequate barriers between occupants and the high voltage systems are necessary to provide protection from potentially harmful electric current and materials within the high voltage system that can cause injury to occupants of the vehicle during and after a crash. This SAE Recommended Practice is applicable to Electric, Fuel Cell and Hybrid vehicle designs that are comprised of at least one vehicle propulsion voltage bus with a nominal operating voltage greater than 60 and less than 1,500 VDC, or greater than 30 and less than 1,000 VAC. This Recommended Practice addresses post-crash electrical safety, retention of electrical propulsion components and electrolyte spillage.

J2344: Guidelines for Electric Vehicle Safety

This SAE Information Report identifies and defines the preferred technical guidelines relating to safety for vehicles that contain High Voltage (HV), such as Electric Vehicles (EV), Hybrid Electric Vehicles (HEV), Plug-In Hybrid Electric Vehicle (PHEV), Fuel Cell Vehicles (FCV) and Plug-In Fuel Cell Vehicles (PFCV) during normal operation and charging, as applicable. Guidelines in this document do not necessarily address maintenance, repair, or assembly safety issues..

J2910: Recommended Practice for the Design and Test of Hybrid Electric and Electric Trucks and Buses for Electrical Safety

This document will cover the aspects of the design and test of Class 4 through 8 electric and hybrid-electric trucks and buses for electrical safety. The document is intended to address the safety concerns of electrical systems in commercial vehicles that employ voltages greater than 60 VDC or 30 VAC RMS.