Battery Safety Science Webinar Series
Advancing safer energy storage through science

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Electric Vehicle Fire Data and Concerns for First and Second Responders

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Practical Electric Vehicle Firefighting
An ISO 17840 based class

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NTSB Engineering National Resource - Retired

Safety Risks to Emergency Responders from Lithium-Ion Battery Fires in Electric Vehicles
NTSB SR-20-02, 11/13/2020
Resources

NFPA

Training developed with manufacturers, agencies, and organizations
Trained >1900 trainers in majority of States
>30,000 trained

Extensive resources
Online info
Online classes
Field emergency guide

SAE J2990
Hybrid and EV First and Second Responder Recommended Practices

UL FSRI - Firefighter Safety Research Institute
Firefighter research and training is online and free

www.EVSafetyTraining.org

www.ulfirefightersafety.org
Two firefighter demographics

1,115,000 total, 67% are volunteers, 92% male

Location:

About half in rural community <2,500 population, majority are volunteers
About 2/3 of US population served by professional or mixed departments

Education:

High school with non-degree EMT award and specialized training
More of professionals have bachelor degrees in:
  Business (22%), Protective Services (18%)

Age and experience:

27% between 30-39 years old,
41% with >10 years experience

Volunteer:

Most common non-FF employment: #1 Repairing, #2 Equipment Maintenance

Source: NFPA Feb 2020 based in 2018 data
The "only" two firefighter EV concerns and issues

1. **Fire** related concerns
   - What is a battery? What does one even look like?
   - What is an EV and how are they different than a "normal" car?
     - Most volunteer FF are employed in repair fields
   - What burns and how?
   - Will it explode?
   - Stories and urban legends
   - How bad is the smoke?

2. **Electric** related concerns
   - Is the hose stream electrified?
   - Is the vehicle body electrified?
   - Is fire while hooked up to a charger a hazard?
   - What is trapped energy and why is it a hazard?

**Firefighters need more knowledge to even know what concerns they should have around an EV**

3. **Tactical** concerns
   - How to approach an EV?
   - How to identify an EV?
   - Move or immobilize?
   - How to disable the HV hazards?
   - Threats to extricating victims?
   - How close can FF get?
   - Dismay at lack of design standards threatening responders and victims
   - Working around trapped energy?
   - Why won’t it go out? Targeting separate fuels in a fire
   - Need for additional FF for oversight

4. **Situational** concerns
   - How does EV firefighting fit into hundreds of years of training?
     - CTIF — International Association of Fire and Rescue Services
     - ISO — International Standards Organization (Ref. 17840)
     - SAE — Society of Automotive Engineers (Ref. J2990)
     - NFPA — National Fire Protection Association
   - What EVs tend to have fires and where?
   - What’s typical versus how bad can an EV fire be?
   - Complacency
   - EVs other than cars?

What needs to be done?

Fear of the unknown – Will it bite me?

What needs to be done?
1. Fire-related concerns
Three cell shapes/formats

Hazard typically is based in chemistry and not format

**Pouch cells** are least expensive to manufacture. Used in cars, cell phones, and tablets.

**Prismatic cells** frequently used for large & industrial batteries.

**Cylindrical cells** shown as an assembly with a battery management circuit board for charging.

Typical vape, power tool, or mower battery.

What does an EV battery even look like?

Cells versus assemblies

1. Fire concern

The GM “Ultium” is shown below.

PHOTOS REMOVED
What is in a lithium-Ion battery

Cells are designed to vent and may burn but not be explosive

**Cathode (+)**
- Aluminum foil with oxide coating

**Separator**
- Porous *polypropylene* membrane (typ.)

**Anode (-)**
- Copper foil with porous carbon coating

**Electrolyte** = light *oil* that feels like diesel fuel
- Carries dissolved lithium salt ions
- *(NO FLAMMABLE METAL IN RECHARGEABLE CELLS)*

**Mythbusting**

1. **Fire concern**
   - Why does a battery burn?

Each cell contains the complete fire triangle:
- Flammable electrolyte and plastic separator as fuel
- Oxygen from process
- Heat in short circuit
Flammability and hazards vary
Many types of battery chemistry
Shows delivered power & energy of various types

1. Fire concern
Do all batteries burn?

Trade-offs of variables
to meet design goals

Variables include:
Weight
Temperature tolerance
Maintenance
Voltage
Recycling

Specific Energy
Range
Life span
Cost

Specific Power
LNCA
LiFePo
Lead

Fast charge
Phone, toys, & consumer items
Phones, toys, & consumer items

Faster charging
Increasing hazard

400 miles
Leads acid & AGM

Early EV & PHEV
<80 miles

Car battery

PHOTO REMOVED
Thermal runaway process

Layers:
- Cathode (+)
- Separator
- Anode (-)

1. Damaged separator allows current to rush between anode and cathode
2. Heat generated expands hole and melts progressive separator layers, expanding current rush
3. Electrolyte ignites when flammable limit is reached
4. Pressure in cell increases until it vents or bursts

A. Typically some damage creates short circuit within a cell
B. Heat energy
C. Smoke/Flames

Temp <100°C can stop thermal runaway process
Introduce "thermal runaway" concept with small cells

Lithium Ion cells contain both electrical and chemical energy

Internal short circuit (ISC) heat may ignite electrolyte. Heat ignites adjacent cells.

Venting of electrolyte may heat and smoke without ignition or it may ignite.

1. Fire concern with small cells
   What burns and how?

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Thermal runaway in large cells

Cells vent at intervals as each sequentially heats. Vent like roman candles. Smoke is flammable & toxic. Burning plastic and electrolyte can spit from case.

1. Fire concern for big cells
What burns and how?

- Heat and smoke
- Time: 8 cells ignited at 15 minute intervals
Initial battery smoke content

Think plastic fire with nasty additives

Depends on constituent materials

Spectrum analysis of burning batteries found:

- Carbon Monoxide
- Carbon dioxide
- Methane
- Ethylene
- Acetylene
- H₂O
- Dimethyl carbonate
- Ethylmethyl carbonate
- Eye & lung irritating acids

Can not breath

Can ignite

Hazardous Materials

Soot may contain cobalt oxide, nickel oxide, manganese oxide, and other heavy metal skin irritants

WEAR YOUR SCBA & COVER ALL SKIN

1. Fire

Relating smoke hazard for firefighters who regularly smell smoke

Electric Vehicles

Electric vehicles move by power of a traction battery

Normally have TWO batteries,

1. Cabin & systems,
   - 12V
2. High Voltage (HV) Traction, 355 to 560+ volts

Battery Management System (BMS) integrated or separate

EV WITH BATTERIES BUILT INTO BODY (TYPICALLY OLDER)
"INTEGRATED" STYLE

FF Risks:
12V Battery activating airbags & restraints
Burning plastics
HV Traction battery fire
Electrocution by high voltage
Arc Flash

BATTERY/MOTOR ASSY BENEATH BODY
"ROLLER SKATE" STYLE

Orange denotes high voltage >30 VAC or 60 VDC

12V Battery
Inverter

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Ford E-Focus

VW ID.3
2. Electric related concerns

Will it bite me? What firefighters want to know
Electrical concerns for firefighters

12V battery controls safety devices:
Airbags, seat belt pretensioners, door locks

EV will have a HV traction battery
Typically 300+ Volts

HV battery "Stranded energy"
Electrocution
Concerns at hose nozzle
At or in the vehicle

Arc flash

Re-ignitions

Burned three times including 6 days after accident

Exposed HV

HV battery twisted into structure
EV Battery safeguards

Upon impact 12V Safety Response System (SRS) **should**:
- Deploy airbags. **DANGER:** Two stage airbags remain dangerous with 12V available
- Unlock doors
- Retract seatbelts

In EV the BMS opens battery contactors. **DANGER:** Welded contacts can power cables

**DANGER:** Trapped energy and arc hazards

Battery Management System (BMS) controls charge and discharge.

Manual maintenance disconnect can open HV circuit

Firefighter cut loop is 12V to remove BMS power & open contactors
Stranded energy - Electrocution at or in vehicle is possible

1. The car structure and occupants should not be electrified to touch

2. Electrical
   Major concerns about contacting vehicle

2. Risk is from getting between exposed HV parts to become part of the circuit. Examples:
   A. An exposed hand touching orange cables with the other hand on the car body.
   B. Leaning on exposed internal HV battery parts. Internal HV parts may not be orange!
   C. Standing water charged by HV

Bus bar wrapped in heavy rubber and labeled
Beware of high voltage dangers

High power distribution module
3 phase inverter beneath
360V Aux Pwr Module

2. Electrical
Damage may add hazards to crash vehicles
Responder actions may create hazards

Cut loop over orange cables
Debris found loaded on deformed battery

Arc flash hazard - Do not do this!

Plastic insulation may be broken or burned away

12V battery cable and HV cables crushed together

Front impact damage

Chevy Bolt EV

Tesla Model S

Source: NTSB docket HWY18FH013
Source: CoPart
Stranded energy is a shorting and **arc flash danger!**

Car struck concrete wall at 86 mph. Flooding open area of battery extinguished fire with 200-300 gallons of water.

CBS News photo shown in NTSB report

**2. Electrical**

FF are not aware of this hazard and it needs emphasis

5" Arc hole found through top of battery

85 kWh / 310 MJ

Impact

Arc flash hole into passenger footwell

Cells found in passenger footwell

Source: NTSB docket HWY18FH013

Numbers denote modules

Passenger Seat
Stranded energy is a short circuit and **arc flash danger!**

Also an example why you should never attempt to pierce a battery.

Note how few modules were consumed. Missing insulation created potential HV shorts.

167.3 Volts in this module **days after the accident!!**

Plastic insulation burns away, allowing cells to short. **Do not step on or press on damaged batteries.**
EV Charging stations

Vehicle:
Is disconnection during charge a hazard?
How to physically disconnect?

Chargers and cables:
When are the HV cables charged?
Can cable be cut?
How to turn off power to the station?
What HV is at a damaged charger?

Blue or green LEDs denote charging in process
But colors are not standardized

Note: <60A no permit needed per NEC.
Local codes apply

2. Electrical concerns
Lack of standards in status colors,
Lack of physical protection,
Lack of electrical protection,
Lack of emergency shutoff
Common US chargers:

No protective vehicle barrier for many
HV source enters base, below contactors
No visible emergency "panic buttons"
3. **Tactical** concerns
Approach hazards

Same as in ICE vehicles
- Approach from 45 degrees
- Wheel chocks
- Set parking brake
- Vehicle into park
- Turn off ignition
- Disconnect 12V battery

EV sides add hazard:
Battery venting - Note that fire is beneath doors

EV adds front and rear hazards:
Venting fire at front in impact damaged areas
Some vehicles may vent at rear
Fuel tanks in hybrids and hydrogen vehicles
Rolling vehicle hazard (throttle is electric)

EV charging station power is high voltage

Hydrolysis can create flammable gas
Fire took hours to extinguish
Identifying vehicles with traction batteries can be hard

3. Tactical Concern for identifying hazard type
Only one of these variants has had fires

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Clues beyond the badging:

**Orange color**
Name badge clue is missing

Orange denotes high voltage >30 VAC or 60 VDC

**Charge port** in front of driver door (Ford, Chevy), nose (Hyundai, Kia, Nissan), or left tail light (Tesla)
Port displaced into door hinge

3. Tactical
Concerns about design versus damaged

Shades of orange vary

Seeing leaked "coolant" can indicate damage to the HV battery and extra care should be taken.
Disabling the 12 volt battery – Not standardized

Example shows variety of Toyota Prius battery locations

- Prius 2003
- Prius 2004 & 2010
- Prius 2012
- Prius 2016

12V battery:
- Deploys airbags.
- Unlocks doors
- Retracts seatbelts
- Opens HV contactors

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3. Tactical concern for both ICE & EV:
The 12V battery controls potential hazards so cable must be cut ASAP. A lack of standards threatens firefighters and victims.

Move key fob or key card far from vehicle
Turn off vehicle
Double cut cables to prevent reconnection
Wait at least a minute before cutting near safety devices after cutting 12V power
Orange means high voltage - Cut loop info

1. Cut loops are control circuits that **do not** contain high voltage
   Airbag deployment should have already restricted HV to within the HV battery
2. The helmet and cutter symbol is an ISO standard so look for it
3. **The shades of orange and tag details vary**
4. Fire may burn tag, leaving ERG as means to find the cut loops

Under hood instruction sticker shows cut locations (Chevy Bolt)

Pre-standard exceptions exist

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Never cut here

Cut only at symbol

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3. Tactical
   A. Need to know what to look for to cut
   B. Common question is wire or bundle
   C. Pre-standards vehicles are in fleet

Source: Chevrolet
HV Disconnects are not standardized and may need tools

1. Pull plugs by hand (typically hidden)
2. Cut loops requiring cable cutter
3. Cut loops requiring circular saw
4. Twist knob by hand (typically hidden)
5. Fuse - hard for gloved hand

3. Tactical
   Variety of HV disconnects

2. Tesla forward cut loop
5. Smart EV

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"Sheets" may lack key details – Try to access full ERG

The full ERG is needed to find the HV disconnect, as shown below

3. Tactical
Missing detail as mentioned in NTSB study
Some disconnects may be impractical to access

Chevy Volt is an example of how impractical some access may with fire present.

To reach disconnect:
- Get past victim(s)
- Open arm rest
- Remove storage tray
- Pull back white cover
- Press a tab
- Pull out the pull plug

3. Tactical
Potentially inaccessible disconnects with fire or damage mentioned in NTSB study

OR
Cut loop hidden in side wall of trunk

Emergency Response Guides (ERG) show where the disconnects are

Google: NFPA EV ERG
Emergency Response Guides (ERG) have critical answers

ERGs assume user is already fully trained and certified for rescue.

ERGs **ONLY** provide basic guidance to disable, plus locations of HV components to avoid, such as airbags, inflation cylinders, seat belt pre-tensioners, and areas resistant to cutting.

Problem is in variations, even between different years for the same make and model.

Most ERGs are linked at the NFPA Website. Google: NFPA EV ERG


4. Operational

FF not yet aware of resources

Downloadable response guides from Tesla:

- Emergency Response Guide: Tesla Model S EV 2017 - 2018
- Quick Response Guide: Tesla Model S EV 2018
- Emergency Response Guide: Tesla Model S EV 2016 - 2018
- Quick Response Guide: Tesla Model S EV 2016 - 2018
- Emergency Response Guide: Tesla Model X EV 2016 - 2018
- Quick Response Guide: Tesla Model X EV 2016 - 2018
- Quick Response Guide: Tesla Roadster EV 2010 - 2013

About the Program

Emergency Response Guides

NFPA actively maintains a collection of Emergency Response Guides. The guides are free to download. To access, visit the NFPA website.
Minimal electric hazard at hose nozzle

Water shorting of cells within the battery case creates a closed circuit

Two examples of test results:

1. <0.4V and <2 mA reached nozzle in testing by Maryland Research Fire Institute (MRFI) on electric vehicle batteries up to 400 VDC. (Photos below)


2. Water found safe to use at 10 feet on a 1,000 volt (1 kV) source with jet or spray.

   Conclusion of testing by Amped I, LLC, for ConEdison on Feb 3, 2018 pertaining to stationary Essential Supply System (ESS)

Standing in charged water may be a hazard

Batteries can re-ignite after water drains away
This battery re-ignited 22 hours later

MRFI Measurement of electrical energy reaching nozzle found safe levels of energy

3. Tactical
   Major concerns about electrocution hazards

Inability to draw down stranded energy

3. Tactical

Inability to remove trapped energy hazard

Factory provided resistor bank could not reach isolated modules

Ad hoc resistor ineffective
Would take weeks

Saltwater immersion can be effective
1. For the cells/modules the water can reach
2. Requires a week of time
3. Can release hydrogen
Cars now have multiple fuels

1960  20 Lbs  Plastic plus gasoline
2020  ~772 Lbs  Fuel fire then plastic fire
Almost 50% volume with only 10% weight

Current car fires are like dumpster fires.
A metal box of burning plastic.

3. Tactical
Be aware of WHAT is burning
Battery? Plastic interior? Surroundings?

Source: American Fuel & Petrochemical Mfg Assn (AFPM)
Lifting and shoring

Chevrolet Bolt EV
lift points in ERG

Hyundai Kona EV

3. Tactical
Can extrication damage HV battery?

Tesla Model 3

Source: Chevrolet

Source: Tesla
Cuts near charge ports at door hinges and HV cables

Normally unpowered without charger station providing data signal to BMS
If no ERG and in doubt can cut at B pillar and force door(s) open
Avoid cutting the door sills or rockers

Chevrolet Bolt EV

Tesla – HV Cable is in door sill near door catch

Tesla – ERG will show which models have a secondary FF cut point in rear door sill to isolate the HV battery

3. Tactical
Concerns about cutting in vicinity of HV for extrication
Extrication

Much like any other vehicle once electric aspects are accounted for.
Use the ERG to know where HV hazards are
Be aware of smoke, sound, and leaking fluids!

3. Tactical
Concern about venting smoke/flame

Fire blanket may be placed over door sill in case battery vents
Fiberglass blanket can add additional (poor) electric insulation layer

Individual cells may launch
Hazard is the burning electrolyte
Water in vehicle cabin does not reach cells

The body is a tub and separate from the sealed battery beneath

This will only address the body plastics fire (Class B)

Because water will not reach cells

3. Tactical
How to extinguish a battery fire

Cool the bottom
If the battery is a fuel

Layers between cabin floor and top of sealed battery case
Try to get water into the battery case if possible
Some new EVs have a designed opening for firefighting. Consult ERG

Concentrate water at exposed cells to flood battery case

3. Tactical
A. Concern about effective water usage
B. Concern about how to use foaming agents

Use only enough to help wet and penetrate
Do NOT to trap heat with foam

Venoting indicates where case was open

Related note – MSDS for Tesla Powerwall ESS recommends getting water into racks
Alternative- Submerge the battery

European method for fast result addresses both battery and plastics

Water electrolysis may create flammable gas after removal

3. Tactical
Awareness of an effective alternative

Ad hoc using a dumpster

Adding salt to water has been used to drain trapped energy with time
Operations

4. Situational concerns
How to fit into existing firefighter work flow

Two major accomplishments for EV firefighters:

2015: ISO 17840 - Information For First And Second Responders, Road Vehicles
0. Rescue Sheet(s)
1. Identification / recognition
2. Immobilisation / stabilisation / lifting
3. Disable direct hazards / safety regulations
4. Access to the occupants
5. Stored energy / liquids / gases / solids
6. In case of fire
7. In case of immersion
8. Towing / transportation / storage
9. Important additional information
10. Explanation of the used symbols

2018: NFPA collected manufacturer emergency information

4. Situational
Firefighters know this work flow so EV responses need to fit into it
Background: When & where have EVs caught fire?
Over half of cars burnt were on charge or not moving
Most vehicles were under two years old
Background: Which burn more often?

**No data separates the electric from gasoline drive components**

Sample of total (not just burned) U.S. salvage vehicles equipped with traction batteries:

<table>
<thead>
<tr>
<th>Make</th>
<th>Count</th>
</tr>
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<tbody>
<tr>
<td>Tesla</td>
<td>142</td>
</tr>
<tr>
<td>Toyota Prius</td>
<td>679</td>
</tr>
<tr>
<td>Lexus</td>
<td>122</td>
</tr>
<tr>
<td>BMW</td>
<td>54</td>
</tr>
<tr>
<td>Infinity</td>
<td>9</td>
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<td>Mercedes</td>
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<tr>
<td>Acura</td>
<td>4</td>
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<td>Volvo</td>
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</tr>
<tr>
<td>Cadillac</td>
<td>1</td>
</tr>
<tr>
<td>Jaguar</td>
<td>1</td>
</tr>
<tr>
<td><strong>Total Hybrid</strong></td>
<td><strong>833</strong></td>
</tr>
</tbody>
</table>

Only fully electric vehicle on list:

- **4. Situational**
  - Data does not differentiate
  - 12V Battery versus
  - HV battery versus
  - ICE engine

* Copart data obtained 6/20/2019 regarding salvage vehicles with fire loss for all reasons, including arson and adjacent to other fire. Photos by Copart.
Complacency is a FF concern

Salvage records show only 1 in 143 wrecked EVs experienced fire

Note: This does **not** mean they became salvage **due to** fire.

Typical EV accident

The driver walked away
No smoke
No fire

4. Situational

Complacency due to low ratio of fire events

* Copart data obtained 6/20/2019 regarding salvage vehicles with fire loss for all reasons, including arson and adjacent to other fire
Give battery-powered vehicles space
Venting and thermal runaway – NO explosions – Exceptional bad day example

Clue to move away fast:
Watch for flash of van tail lights, venting sound, smoke, pressurized vent flames

Watch for quieter periods followed by venting of additional modules

Watch for truck fuel shift from plastic to battery venting

4. Situational
Video shows how bad situation can get and how much room is needed
Should vehicle first be immobilized or moved?

Potential to do injury
Potential structures to ignite
Need space to work

Confined space

4. Situational
Need for continuous oversight because firefighters will press forward

This FF can not see venting flames underneath

Once in place, always block the wheels to prevent movement. EVs have electronic controls and car can move silently.
Extinguish

Think of individual fuels

Key for battery is to stop or slow propagation between cells

**Aggressive Method:** Plan on LOTS of water
(ABC Dry chemical is ineffective)

or

**Defensive Method:** Let it burn out if isolated

4. Situational

A. EV responses need to continually be aware of what fuel is burning. The background photo has three separate fuels in the battery, plastics in car, and house structure.

B. Responders have two opposite ways to deal with EV fires
1 in 8 EV fires are commercial vehicles

Trucks and busses
Bigger batteries operating with or near greater numbers of people

4. Situational
Most people are unaware of commercial EVs

By Vehicle Type
- Car/Pickup: 87.6%
- Bus: 6.6%
- Truck: 5.8%

Modular chassis (Volvo) for box trucks, trash trucks, etc

Source: Frederick News Post

Source: Peterbilt

Source: Volvo
Li-ion already unseen in use on busses, trucks, and rail

Replacements for lead acid and Ni-Cad non-traction batteries
Cab controls, HVAC, and radios for 6 hours (advertised)

4. Situational concerns
Smoke from large formats with passengers, in tunnels limits vehicle access, may limit battery access

Plan responses:
In a tunnel?
With smoke?
Flame?
Passengers?
Third rail?
Concern about large batteries being introduced

Lithium hybrids in US market as yard engines
Commuter light rail
Locomotives used in Europe
Caterpillar locomotive up to 2.2 MW
GE up to 2.4 MW

4. Situational

About here students' eyes get big

New York MTA hybrid engine

GE Transportation's Battery-Electric Locomotive

- Massive power generation capabilities up to
- Huge fuel savings of at least 10-15%
Summary and Investigating an EV fire

Source: COPART

Fort Lauderdale FL, NTSB HWY18FH013
Thank you for your time.

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