RESEARCH FOUNDATION
RESEARCH FOR THE NFPA MISSION

EV Fire Characterization, Firefighting Tactics & Stranded Energy Assessment

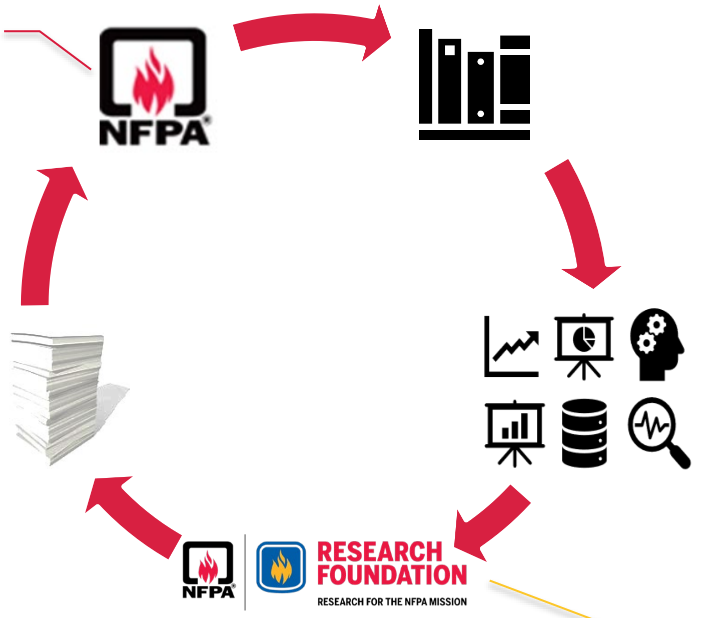
US DOT Battery Safety Post-Incident Stakeholder Meeting

August 27, 2024 | Victoria Hutchison, Fire Protection Research Foundation at NFPA

Relationship between NFPA and FPRF

NFPA vision: Be the leading global advocate for the elimination of death, injury, property, and economic loss due to fire, electrical and related hazards.

NFPA mission: To help save lives and reduce loss with information, knowledge, and passion.



Mission: The Research Foundation's mission is to plan, manage and communicate research in support of the NFPA mission.

Vision: To be the premier global research delivery organization for the elimination of death, injury, property and economic loss due to fire, electrical and related hazards.

FPRF

- Independent non-profit organization
- Formed by NFPA in 1982
- Intended to provide data to support the needs of NFPA codes & standards
- Research funds come primarily from:
    - Private/public sector consortia
    - Grants/gov't sources,
    - Other sources (including NFPA)

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EV vs ICE: Similarities and Differences

EV

- ✓ Potential toxic gas release
- ✓ Possible vapor cloud explosion
- ✓ Intense jet like, highly directional flames, can burn for extended period of time
- ✓ High temp. flames (~1000+ C)
- ✓ High HRR: can be up to ~8 MW or higher
- ✓ **Battery cell debris** projectiles possible during **thermal runaway**
- ✓ **Reignition Risk**

ICE

- ✓ Potential toxic gas release
- ✓ Possible deflagration risk (from fuel)
- ✓ Intense flames – often short lived following suppression
- ✓ High flame temperatures (~1000+ C)
- ✓ High HRR ~ can be up to 8 MW
- ✓ Risk of releasing debris during fire

Hazard Comparison Summary: EV vs ICE

	EV	ICE
Fuel Source	Lithium-ion Batteries	Gasoline
Fire Causes	Puncture, overheating, overcharging, over-discharging	Fuel or oil leak, overheating, worn out parts, loose electrical components
Likelihood	*** 25.1 fires/100,000 cars sold ***	1,529.9 fires/100,000 cars sold
Suppression Time	~ 60 – 90+ min	~ 30 min
Water Usage	Reports of up to thousands of gallons; Sustained water supply needed	~500 gallons
Reignition Potential	Likely, or common	Rare
Fire Size	Can be large if propagation occurs, Avg HRR: 1.5 – 8+ MW Avg THR: 5.9 GJ	Typically limited to 1 vehicle; propagation is less common Avg HRR: 6.5 MW – 8 MW Avg THR: 5.9 GJ

** not based on national statistical data

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Hazard Characterization Summary: EV vs ICE

	Electric Vehicles (EV)	Internal Combustion Engine (ICE)
Toxicity of Runoff	Water runoff had a pH of **7.3 - 7.7** copper, antimony, and higher concentrations of manganese, nickel, cobalt, hydrogen fluoride, and lithium	Water runoff had a pH of **2.6 - 2.8** Higher concentrations of lead, copper, polycyclic aromatic hydrocarbons, and volatile organic compounds, testing showed higher toxicity towards aquatic species
Special Post-Fire Considerations	Often towed and recommended to be placed **50 ft away** from all surroundings (due to reignition risk)	Vehicles/engines should be inspected to see how much damage was done to determine if repairs can occur
Additional Hazards	**Stranded energy**, electrocution, second responders, projectiles and explosions, propagation, toxic gas release	Toxic gas release, lots of combustible fuel still accessible to the fire (i.e., a full gas tank)

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Common Questions with EV response

Fire Service

Putting vehicles into safe states

Identifying the hazards

Confidence in EV firefighting response

Communicating hazards downstream

Tow & Recovery

Collision Center

Dismantler

Recycler

- Instructor-led Classroom Course
- Online Training / Simulations
- Interactive 3D Models
- Educational Videos
- Quick Reference Materials
- Gamification Training

https://www.nfpa.org/ev

NFPA

ALTERNATIVE FUEL VEHICLES

SAFETY TRAINING PROGRAM

NFPA Electric Vehicle Training Portfolio

- 12+ years of development & training,
  ~ 320,000 participants to date
- Major revision of courses 4 times to Enhance & Extend Scope of Training
- Includes 1st & 2nd Responders (Fire, EMS, Tow & Crash Reconstruction & Fire Investigators), Insurance, Mechanics, Code Officials, Charging Station Installers, Utilities, Auto Manufacturers, Dealerships, Public.
- Holding Community EV Preparedness Workshops & Training in 30 States (2023-2024) w/ Clean Cities Coalitions
- Current Activities: NFPA tested the latest Distributed Energy Resource equipment in controlled structure fires and related incidents, developed modularized courses on DER safety for easier consumption, and created a multiplayer serious **gaming platform** with several energy-related incidents at each scene.


ck Officer 2
Truck Officer 1

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NFPA EV Training

Module 1: Intro to EV FF Safety

Module 2: EV Basic Electrical Concepts & Hazards

Module 3: P/HEV and EV Systems, Identification and Safety Features

- Safety Features and Identification Objectives, Terms and Definitions
- Categories of HEV, PHEV, & EV
- EV components and hazards
- Charging Stations
- First Responder challenges

Module 4: Initial Response: Identification, Immobilization & Disabling Procedures

Module 5: Emergency Operations

- Emergency Operation Objectives
- HEV/EV Extrication
- Partial/Full Water Submersion
- Emergency Operation Activity
- Fire Extinguishment Techniques (Vehicle and Lithium Ion & Nickel Metal Hydride Batteries)
- High-voltage Battery Breach
- Vehicle Fires & Reignition
- Charging Station Incidents
- Post-Incident Vehicle Handling

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Current Recommendations

General Procedures

- Use standard vehicle firefighting equipment and tactics in accordance with department SOPs/SOGs.
- Hybrid/EV fires don't require special equipment for fire suppression/ extinguishment.

PPE

- All personnel should wear full PPE & SCBA as required at all vehicle fires.

Extinguishing Agents

- Use water or other standard agents for vehicle fires.
    - The use of water does not present an electrical hazard to firefighting personnel.
    - If an HV battery catches fire, it will require a large, sustained volume of water.

Warnings

- Use a **large volumes of water** on a HV battery fire to cool the battery & prevent release of toxic gases.
- **Reignition is possible** after HV battery fire extinguishment.
    - Use thermal imaging to monitor the battery.
    - Do not store a vehicle containing a damaged or burned Li-Ion HV battery in or within 50 feet of a structure or other vehicle until the battery can be discharged.

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Current Recommendations

Tactics

- DO NOT blindly pierce through the hood with tools such as a Halligan bar to gain access. This tactic presents a severe shock hazard.
- **Offensive Attack**: Recommended where exposures are present or the high voltage battery is not involved.
- **Defensive Attack**: Recommended if the high voltage battery is involved and no exposures are present. Due to the difficulty in reaching the burning cells inside the battery with the extinguishing agent, the Incident Commander may choose to allow it to burn itself out

Overhaul/Recovery

- Immobilize/disable the vehicle.
- Never disconnect or contact any exposed high voltage components or wiring.
- Contact a mfg representative asap to help with post-incident vehicle disposition/de-energizing the high voltage battery.
- Never breach or remove the HV battery
- Do not store a damaged/burned P/HEV/EV within 50 ft (15m) of a structure or another vehicle until the battery can be discharged.

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Current FF Practice for EVs

Current best practice for EV fires:

Apply copious amounts of water onto the battery/source of the fire for an extended period of time.

Water remains the primary suppression method because it is:

simple,

cheap,

effective,

easy to access/use.

Some challenges exist:

Required amount of water typically exceeds the amount stored in the tank of a fire truck.

Thousands of gallons of water may be required; can be difficult to get this quantity of water from hydrants/other source

This traditional suppression method can take several hours to fully put out an EV fire and has been shown to still result in reignition.

Using copious amounts of water on EVs can cause water runoff, which can be highly toxic and hazardous due to the chemicals leached from the batteries.

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FPRF Research on EV FF Tactics to Address Critical Gaps

Goal: Develop the information necessary for improving efficiency and safety during response to high-voltage lithium-ion battery EVs by:

- Determining the effectiveness of current firefighting techniques,
- Evaluating new technologies and practices, and
- Determining the impact of suppression activities and risks associated with stranded energy and re-ignition.

DHS/FEMA AFG Award: EMW-2021-FP-00948

Research/Testing Focus:

- Are the traditional approaches optimal?
- What other options are available?
- How do they perform in comparison, in terms of damage reduction, fire extension, resources required, etc?
- What is the impact of various suppression tactics on post-incident reignition risk?

Research & Testing Scope

- Let it Burn
- Direct Suppression → Agent → Application
- Indirect Suppression → Agent → Application
- Submersion → Brine Considerations → Performance Keys
- Containment → Performance Criteria → Hazard Potential

Impact on:

- Damage reduction/Fire extension
- Tools/Resources required
- Residual Stranded Energy
- Environmental Considerations
- FF Risks
- Time
- Etc.

Direct and Indirect Cooling/Suppression

Considerations

- Interior Attack
- Exterior Attack
- Application
- Water vs Agent
- Volume
- Run Off

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Submersion

Considerations

- Deployment
- Brine Details
- Discharge
- Hazards
- Effectiveness
- Battery Design

Fire Blankets - Containment

Considerations

- Blanket Design
- Gas Containment
- Vapor Hazards
- Cooling Affect
- Applications

Extinguishing Lances

- The device penetrates the vehicles battery pack using manual or pneumatic force from inside the cab or from underneath.
- Can be attached to a long hose to flood battery with water, extinguishing the fire while cooling the battery from a distance.
- Firefighter, must be close to the burning EV to install the extinguishing lance, but after installation is ideally kept a safe distance away.

Case Study by Swedish Civil Contingencies Agency

- Consistent heavy flow of water through battery can be effective and fast at mitigating TR & damage/injury
  - Battery flooding reduces time required to suppress fire
  - Increased tendency for jet flames to shoot out of battery
  - Reported greater electrocution exposure to firefighter because of current remaining in battery

https://www.murer-feuerschutz.de

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Cold Cutting

Concept

- Similar to extinguishing lance
- Abrasive water jet is used to cut through layers of steel to penetrate surfaces in an EV and access the battery pack.
- Allows for rapid access to the fuel source (reduces risk of flashover or backdraft)
- Maximum working pressure for cold cutting is 300 bar (can cut through 15cm of concrete in 75 s)

Important Consideration: Gasses

Vapor Cloud

- Suppression Impact
- Hydraulic Ventilation
- Exposure Risks
- Extinguishment Validation
- Atmospheric Monitoring

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Important Considerations: Gasses

Ventilation is critical to manage explosivity and toxicity

Chemistry, State of Charge and Energy Density directly affect gas production and fire behavior

Explosivity: Total hydrocarbons mimic methane or propane with a broader flammability range of 6% - 40% LEL/UEL.

Gas production is approximately 1 – 5 L of gas/watt hour

Asphyxiants present: CO, HCN

Irritants present: Nitrogen oxides, SO_2, HCl, HF

Incomplete combustion produces a more hazardous environment from an atmospheric perspective

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Important Considerations: Run Off

Water Considerations: Flushing or soaking of the battery significantly increases water contaminants.

Water Ph 0f 7.5 – 8.0 is typical (Alkaline). Normal Ph range is 6.0 – 8.5 for groundwater.

Metals may be present – Cobalt, Manganese, Copper, Aluminum.
PFAS is present and affected critical areas are similar to combustion vehicles.

Polycylic Aromatic Hydrocarbons are far less prevalent than combustion engine vehicles.

Contain and Collect runoff if water is applied and avoid uncontained submersion or battery flushing without containment and collection.

Post-Incident Handling and Stewardship

Significant incidents will require specialized clean up and post incident management.

EPA and DOT regulations should be strictly followed during cleanup.

These can be time consuming, costly, and disruptive to operations. Mitigation strategies should be developed with special resources as part of the Emergency Response Plan. Good plans will include rapid support for incidents and guidance for First Responders.

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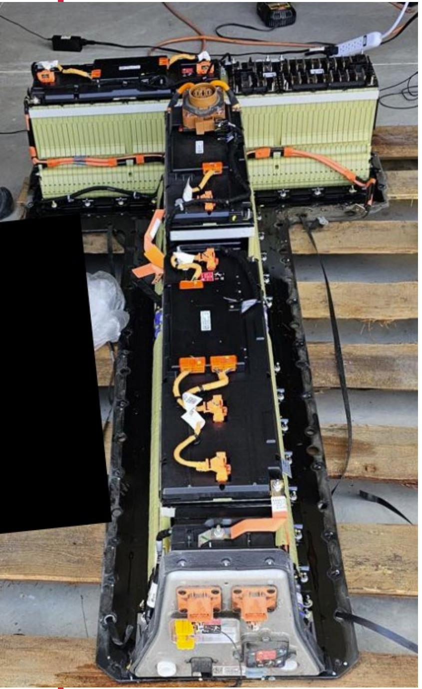
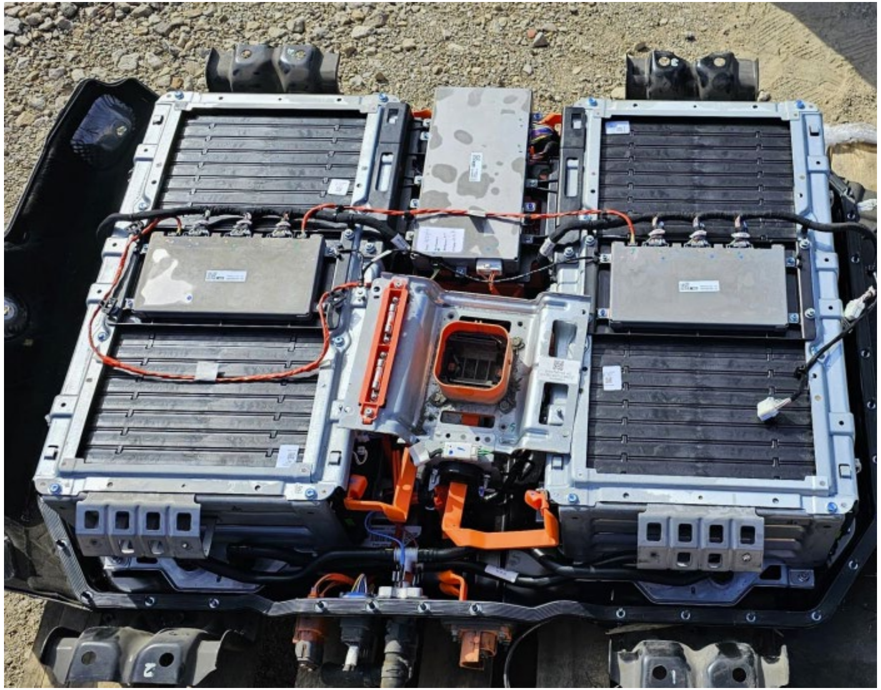
On-going EV Pack and Vehicle Testing





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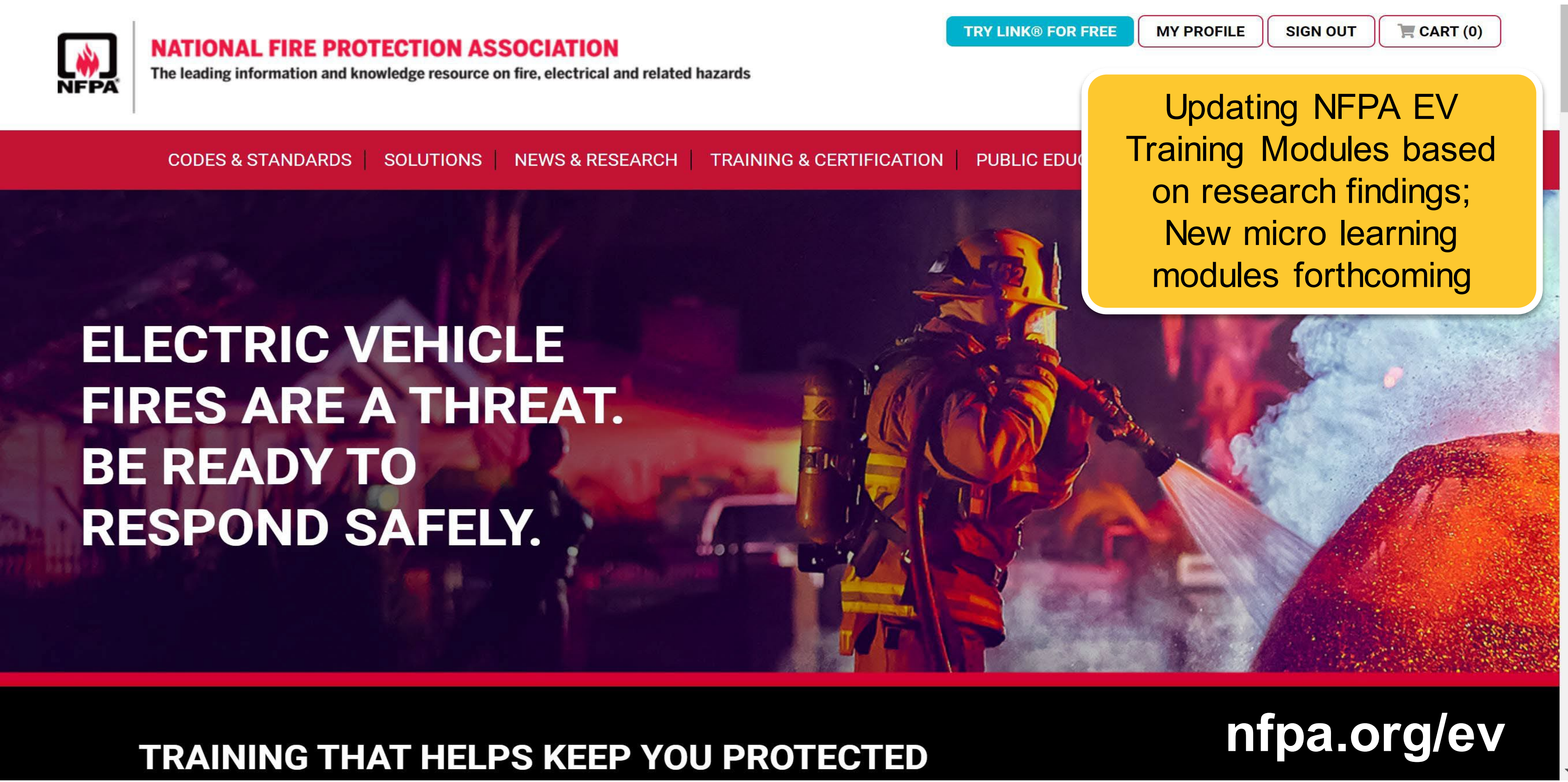
Test Phase	Test Number	Test Scale	Evaluation Type	Hazard Management Type		Initiation Technique	Measurements					
							Temperature	Heat-Flux	HRR	Gas Composition	Mass-Loss	Stranded Energy
I	1	Cell-Pack	Baseline Hazard	None		Overcharge	X	X	X	X	X	X
I	2	Cell-Pack	Baseline Hazard	None		Overcharge	X	X	X	X	X	X
II-B	32	Cell-Pack	Stranded Energy Management	Submersion	Ramped increase of salinity	None						X
II-B	33	Cell-Pack	Stranded Energy Management	Submersion	Ramped increase of salinity	None						X
III	34	Full Vehicle	Hazard Management	None		Internally applied heat	X	X	X		X	X
III	35	Full Vehicle	Hazard Management	Fire Blanket	Determined by Phase II results	Internally applied heat	X	X	X		X	X
III	36	Full Vehicle	Hazard Management	Suppression Agent	Determined by Phase II results	Internally applied heat	X	X	X		X	X
III	37	Full Vehicle	Hazard Management	Appliance	Determined by Phase II results	Internally applied heat	X	X			X	X

Free Burns	Water Only	Agents	Blankets	Tools	Submersion
6 tests (2 per mfg)	3 tests	6 tests	9 tests	6 tests	3 dedicated tests*
EV Mfg represented: 3	**EV Mfg represented:** 3	**EV Mfg represented:** 3	**EV Mfg represented:** 3	**EV Mfg represented:** 3	**EV Mfg represented:** 3
N/A	N/A	2 agents (F-500; E-FireX)	3 blanket mfg represented	2 tools (Cobra; Turtle)	N/A

Measurements					
Temperature	Heat-Flux	HRR	Gas Composition	Mass-Loss	Stranded Energy
X	X	X	X	X	X



Updating NFPA EV Training Modules based on research findings; New micro learning modules forthcoming

nfpa.org/ev

Thank you!

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