DISCLAIMER

NFPA Distributed Energy Resources Safety Training (DERST) For Emergency Responders

Final Technical Report

Project Title: Creating the NFPA Distributed Energy Resources Safety Training (DERST) Program

DOE Award Number: DE-EE0009601

Recipient Name: National Fire Protection Association

Subrecipient Partners: Argonne National Laboratory (Argonne), University of Texas, Austin, the North American Fire Training Directors

Period of Performance: June 1, 2021 – December 31, 2024

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Executive Summary

The National Fire Protection Association, with support from the Department of Energy, executed a multi-year initiative to develop, enhance, and disseminate Distributed Energy Resources Safety Training (DERST) tools for U.S. emergency responders. As Distributed Energy Resources (DER)—such as solar photovoltaics, battery energy storage systems (ESS), electric vehicles (EVs), and associated infrastructure—become increasingly prevalent, the NFPA identified a critical need for up-to-date standardized, accessible, and effective safety training tailored for the fire service and related public safety professionals.

The project delivered a comprehensive suite of educational resources to improve responders' abilities to safely manage DER-related incidents. This included:

- Revised Modular Training Courses: Updated classroom-based DER safety courses, now modular and accessible nationwide through fire academies and the North American Fire Training Directors (NAFTD) network.
- Live Burn Testing & Research: A full-scale controlled burn of a DER-equipped residential structure provided real-world data and insights, forming the basis for updated best practices.
- A Gamified Simulation Tool – Firefighters Incident Response Simulation Tool (FIRST): A first-of-its-kind, multiplayer, scenario-based simulation using the Unreal Engine 5.0 to train responders in a realistic virtual, multi-DER incident environment.
- Field Familiarization Software Tools & Prop Guide: Digital DER field familiarization evolutions software guide and a prop development manual to support field-based DER training exercises, enhancing responders' hands-on familiarity with DER infrastructure and collaboration on virtual incident responses.
- National Dissemination Strategy: Strategic partnerships with NAFTD, Vector Solutions, and others enabled wide-scale distribution, with over 5,000 departments accessing resources and 1,100+ departments adopting the simulator in the first seven months. Also provided a web portal for easy access to all training and simulation programs developed under this grant for the U.S. responder community.

Key findings from the project—particularly from the burn test—led to paradigm shifts in fire response tactics. For example, traditional approaches to garage fires may be hazardous if DERs are present, due to explosive off gassing and thermal runaway risks. The new training emphasizes scene assessment, stand-off approaches, thermal imaging verification, and careful post-incident cooling of DER components to prevent reignition.

This initiative has had a significant national impact, raising awareness, enhancing preparedness, and supporting safer DER incident response practices. Significant engagement from the media, public safety organizations, and PBS coverage has further amplified the reach and adoption of NFPA's DER safety training, tools, and simulations.

Project Introduction

Distributed Energy Resources are small geographically dispersed electricity generators that are connected to a local distribution system. DERs can include solar panels, energy storage systems, small gaseous fueled generators, electric vehicles, and controllable loads, such as HVAC systems, heat pumps, electric water heaters and their control systems. First responders will confront DERs in abnormal events such as fires, chemical releases, mechanical damage, water immersion, and thermal runaway incidents.

During a DER emergency event, the National Fire Protection Association (NFPA) wants to ensure that responders are properly trained to make correct tactical decisions to optimize protection of life, ensure incident stabilization, and conserve property. First responders must understand the control systems and the individual technologies involved with DERs, as well as their interconnections and how to approach an incident scene to maintain as safe a working environment as possible. During this project, NFPA developed a suite of solutions to support the rapid growth of clean energy technologies, which provide the means for educating firefighters, first responders, and other relevant emergency response professionals to handle these incidents more safely and effectively. Ensuring that these stakeholders are trained to understand DER technologies—especially the inherent risks and ramifications of responding to DER incidents—is key to furthering acceptance and implementation of DERs in the U.S.

For more than a decade, NFPA has been committed to developing and delivering DER safety training (DERST) for our nation's emergency responders, as we offer the most popular U.S. responder training programs on handling energy storage systems (ESS), photovoltaics (PV), electric vehicles (EVs), and electric vehicle power supply equipment (EVSE). During this project, NFPA's revised its existing DER training resources to a whole new level by 1) updating and modularizing our objective-based classroom training courses for fire departments across the country; 2) creating a multi-player serious gaming DER incident simulator (the first of its kind—like a flight simulator for pilots), and 3) developing a unique DER Field Familiarization Evolutions & Props guide for setting up the fire service DER site visits which allow running team virtualization exercises to address potential incidents. Together, these freely available resources provide emergency responders nationwide with engaging, innovative, and cutting-edge training and simulations on pre-planning DER installations, visualizing and collaborating on how incidents can be more safely handled, and effectively managing DER incidents on-scene. For responder participants across the country, the results will be increased familiarity with potential DER incidents, greater levels of responder preparedness, and increased acceptance and promotion of these technologies across the US.

Project Goals & Objectives

The objectives of this project were to research, develop, and deploy a suite of Distributed Energy Resources Safety Training (DERST) educational programs and tools for emergency responders surrounding incidents involving battery energy storage systems (ESS), solar/photovoltaic (PV) systems, electric vehicles (EVs), their charging infrastructure (EVSE), and other lithium-ion (Li-Ion) battery-based devices. NFPA explored scenarios that consider the interaction of these technologies when encountered in the field. The DERST will be primarily targeted to firefighters, first responders, public safety officials, and other relevant emergency response professionals. In support of this objective, NFPA constructed its deliverables by:

1) Gathering the latest DER safety research and studies.
2) Conducting multiple live burn field testing of a residential structure in a suburban setting, with the fire service present to extinguish the fire, in order to collect data and arrive at best practices using the latest DER equipment (including an ESS, PV, an electric storage distribution center, an EV, and other commonly found lithium-ion (Li-ion) battery devices in a controlled fire.
3) Updating and modularizing our existing classroom safety programs for the fire service and emergency responders on handling ESS, PV, and EV/EVSE incidents with both NFPA findings from this project and Underwriters Laboratory's (UL) research, test results, and data from a parallel running DOE project, and then distributing the modular training programs across the country.
4) Creating a multi-user and multi-role, scenario-based serious gaming platform for fire departments, based on the collected test results data, to train firefighters together on interactive, real-world, multiple DER incidents in the same structures (approximating flight simulator-style training for a team of firefighters).
5) Developing a Field Familiarization Evolutions web program and DER Prop Guide for safety instruction and incident guidance when conducting DERST tactics education at any DER live training facility – and then deploying these electronic education tools nationwide.

Expected Project Outcomes

1. A report of the DER residential burn study by the University of Texas, Austin (see Appendix A).
2. The development of a revised, modular Energy Storage & Solar Systems Safety classroom course and a revised, modular Electric Vehicle Safety Training classroom course for the fire service, which both incorporate NFPA's burn test results from this project, as well as UL's ESS burn test results in residential settings from a sister DOE Empower project.
3. Distribution of these revised classroom course materials to emergency responders across the nation via the North American Fire Training Directors' network (https://derstfg.org/) and then click on Download NFPA Curriculum).
4. NFPA to design, develop, and deploy a tool that will bridge the gap between the hypothetical training that's currently available and the real-world experience that stakeholders need to truly understand their role in ensuring the safety of their communities with regards to DER-related incidents. NFPA will engage with an instructional design software developer to create a first-of-its-kind multi-player, multi-role, multi-venue, multi-interconnected DER incident gamified training tool. This tool will allow first responders to engage with their peers in real-time as they identify and address the concerns of the DER situation as a team, as they would in an actual incident. To more closely mimic real-world incidents, the scenarios will include multiple DERs in a single incident. The understanding participants will gain from interacting through this training will greatly improve their ability to respond effectively and efficiently to incidents when they occur.
5. The final component of this project addresses the need for firefighters to conduct live field familiarization training to ensure that responders are able to apply their understanding of DER components and incident response best practices attained from the classroom and simulation courses created above, and apply that education to collaborate with their peers -- to visualize the use of safety techniques and tactics learned to effectively deal with hypothetical DER incidents presented by the software. NFPA partnered with NAFTD to create web-based education tools to facilitate the above field evolutions guide, as well as the DERST guide on the Selection and Use of Training Activities and Props, providing responders enhanced safety learnings during a live collaboration training experience with this new technology during field evolutions (www.derstfg.org).

Project Approach

To achieve the goal for this 42-month project, NFPA detailed eleven (11) tasks that supported successful completion of the established project objectives (See Table 1).

Project Tasks	Description
Project Management and Planning	NFPA developed and maintained the Project Management Plan (PMP). NFPA managed and implemented the project in accordance with the PMP standards set forth by PMI.
Kick-Off Meeting (w/DOE)	NFPA participated in a DOE project kickoff meeting within 30 days of project initiation.
1) Held NFPA Partners Kickoff Meeting	Held a Project Kickoff meeting with the partners and stakeholders, determining issues, risks, responsibilities, rules, project schedule and milestones.
2) Conducted DER Fire Testing	Coordinated and conducted state-of-the-art incident testing DERs in controlled emergency fires and incidents. This testing included burning an actual residential structure with multiple DER equipment involved in the fire (including PV, ESS, & EVSE) and uncovered hazards and best practices for extinguishing the structure and DERs effectively and safety.
3) Collected the Latest DER Safety Research	Reviewed and collected the latest DER literature, gathering up-to-date testing, tactics, codes, standards, regulations, and best practices to inform curriculum development.
4) Revised and Updated Existing Train-The-Trainer Classroom Courses	Modularized and enhanced the classroom training with the latest DER tactics.
5) Analyzed and Documented DER Fire Test Findings	Following the completion of the DER Fire Testing, the recipient collected and synthesized all available data received from the burn testing. Analysis was performed and incorporated into the training program development.
6) Disseminated the Classroom Training Materials	DER safety classroom modules were made accessible and propagated across the country to all state and local fire training academies.
7) Onboarded a Serious Gaming Development Vendor	Issued a Request For Proposals solicitation to multiple organizations to find a qualified eLearning/instructional design and development vendor.
8) Developed a Serious Gaming DER Safety Simulator	Conceptualized and developed a multi-player, multi-role, multi-venue, multi-interconnected-DER incident gamified training tool.
9) Conducted a Comprehensive Review of Gaming Simulator	Evaluated the Serious Gaming DER Safety Simulator from a scientific, technical, and responder tactics standpoint during a multi-tiered beta review process prior to delivery.
10) Developed a Field Evolution Activities Software System, Portal, and Props Guide	Conceptualized, designed, and developed a unique guide to responder field familiarization DER evolution activities and prop selection that aids departments setting up offsite field familiarization evolutions at DER sites and training centers.
11) Field Evolution Activities and Props Guide Dissemination	Disseminated the DER field evolution online system and training portal to state and local fire training academies through nationwide outreach, led by the North American Fire Training Directors

Table 1: (Project Approach)

Project Schedule

DOE Award Education Project "NFPA Spurs the Safe Adoption of Electric Vehicles through Education and Outreach"	Anticipated Completion	Completion Dates
Task 0.0) Project Management and Planning	7.15.2021	**7.14.2021**
0.1) Kick-Off Meeting w/DOE	6.15.2021	**6.15.2021**
1.1) Hold Partners Kickoff Meetings	8.31.2021	**8.31.2021**
1.2) Conduct DER Fire Testing	5.30.2022	**4.18.2022**
1.3) Collect Latest DER Research	11.30.2021	**3.31.2022**
1.4) Initiate Revising Existing DER Train-the-Trainer Courses	5.31.2022	**6.30.2022**
2.1) Update of Existing Distributed Energy Classroom Courses	5.31.2022	**12.30.2023**
2.2) Analyze and Document DER Fire Test Findings	11.30.2022	**9.30.2023**
2.3) Dissemination of Classroom Training Materials (**Note:** This activity was held up for 7 months by UL as they were providing us data from their EERE Energy Storage project tests to incorporate into NFPA's training – DOE approved that we wait for UL's results before proceeding.)	1.15.2023	**4.30.2024**
2.4) Onboarding of Serious Gaming Development Vendors	7.30.2022	**9.30.2022**
2.5) Development of Serious Gaming DER Safety Simulator	4.28.2023	**12.30.2023**
2.6) Comprehensive Review of Gaming	5.31.2023	**12.30.2023**
3.1) Field Evolution Activities and Props Guide Development	11.30.2024	**11.30.2024**
3.2) DER Evolution Dissemination & Prop Guide Completed	12.30.2024	**12.30.2024**

Project Activities

The following review of Project Activities and Accomplishments corresponds to task assignments contained within the finalized Statement of Project Objectives (SOPO) dated November 2022.

A. SCOPE OF WORK

The project was conducted in 3 budget periods:

Budget Period 1: Content Collection & DER Fire Testing – Activities in this budget period included the project kick-off, collecting the latest DER safety research, conducting DER fire testing, and revising the existing DER classroom courses and breaking the course material into modules.

Budget Period 2: Gaming Simulator Development and Classroom coursework Dissemination: Activities in this budget period include DER fire test analysis and documentation of fire test findings, incorporating UL's findings into our learning points and training, dissemination of classroom training materials, onboarding of serious gaming development vendors, development of the serious gaming DER Safety Simulator, and comprehensive review of the Gaming Simulator.

Budget Period 3: DER Field Familiarization Evolution Training Development, DER Resource Prop Guide Development, and Public Relations – Activities in this budget period include continued dissemination of classroom training materials and the DER Safety Simulator, development of the Field Familiarization Evolution software and DER props guide development, and their PR and release to US Fire Service.

B. TASKS PERFORMED

Budget Period 1 - Content Collection & DER Fire Testing

Task 0.0: Project Management and Planning

NFPA developed and maintained the Project Management Plan (PMP) for this project using MS Excel, MS Word documents and Milestone Tables, and NFPA's Sprint Tracker system.

Task 0.1: Kick-Off Meeting

The Recipient participated in a project kickoff meeting with the DOE within 30 days of project initiation and completed all requested documentation.

Task 1.1: Held Partners Kickoff Meeting

Assembled subrecipient partners and stakeholders for a kickoff meeting, determining issues, risks, responsibilities, rules, project schedule, and milestones.

Task Activities: NFPA held a kickoff meeting with subrecipient partners University of Texas, Austin (UT-Austin), the North American Fire Training Directors (NAFTD), and Argonne National Laboratory (Argonne), to introduce those working on the project, provide channels of collaboration, outline the scope, objectives, goals, responsibilities, chain of authority, and government rules for operating as subrecipients. All parties participated and were onboard.

Task 1.2: Conducted DER Fire Testing

Coordinated and conducted state-of-the-art incident test DERs in controlled emergency fires. This testing included burning an actual residential garage structure with multiple DER equipment involved in the fire (including PV, ESS, & EVSE) and uncovered hazards and best practices for extinguishing the structure and DERs more effectively and safely.

Task Activities: NFPA held bi-monthly meetings with our subrecipient partners UT-Austin, NAFTD, and Argonne, and our project's SMEs to provide channels of collaboration and continue to make progress toward our plan of a DER residential test fire. NFPA had UT-Austin work with local fire departments to identify a residential structure for burn testing DER systems, located a property slated for demolition, and contracted and permitted for a burn test with the local authorities (Figure 1). DOE requested that our team work with Underwriters Laboratories (UL, involved because of a parallel DOE Empowered grant project), which we did, and together with all our partners constructed a final test plan detailing the DER burn test to be conducted. The purpose of the test was to amass as much information and data as possible during staged DER fire events, which included gas sensor and flame path data and to record Ultraviolet (UV) and color videos as input in constructing a realistic simulation during the development of a serious game DERST incident simulation for the fire service. Much more was learned than anticipated with respect to how the DERs burned, off gassed, and arc flashed, as well as how long it took to actually extinguish the DERs before it was safe to transport the remains.

Figure 1 (Residential Structure for Burn Test)

Figure 2 (EV w/ sensors)

UT-Austin and NFPA chose a residential property within the city of Austin, TX, as the test site. The single-family residential structure had an attached garage. A solar panel system was already installed on the roof. NFPA purchased and installed an energy storage system (a new LINIOTECH 10 KWH LIFEPO4). The team also purchased an electric vehicle and stripped it of its insignia markings (GM Bolt), parked it in the garage, and wired it to many sensor arrays

(Figure 2). Argonne also donated a Level 2 charging station and it was installed in the garage.

Figure 3 (Sensor Array)

UT-Austin took weeks to prepare the structure for the test fires, and wired hundreds of sensors and cameras throughout the structure and on the DERs involved (Figure 3), and an ESS was mounted and connected on the garage wall (Figure 4). Cardboard Boxes filled with flammable polystyrene containers were donated by UL to simulate other flammable paraphernalia found in a typical garage, and a hoverboard and various Li-ion tools were positioned in the garage as well. A battery electric drill was set up to overcharge, which was the ignition system designed to start the fire in the structure's garage.

Figure 4 (ESS Mounted in Garage)

On April 18, 2022, UT-Austin and the Austin Fire Department successfully conducted a residential structure burn test at 4709 Pinehurst, Austin, TX, with DERs (ESS, Solar PV, EVSE, and EV) connected throughout the structure (Figure 5).

Figure 5 (Fire Started in Garage)

The Austin Fire Department flew three drones over the site during the tests, which recorded a video of the incident, UV video of the fire's path and progress, as well as measurements of air quality. Loud explosions and a raging fire enveloped the garage for approximately 45 minutes before the fire department deemed the fire unsafe for the surrounding community and extinguished the blaze (Figure 6). The Austin Fire Department extinguished the structure within half an hour and deemed the fire was out within forty-five minutes, or so they believed.

Figure 6 (Garage DER Fire - Melting Metal Door)

Figure 7 (Remains of ESS)

After the structure was deemed safe, the fire department attached chains to the EV and the ESS and, after multiple attempts, pulled both out of the garage and onto the adjacent driveway for inspection. Both devices appeared completely burned up, with only the metal casing and skeletal structures remaining (Figure 7 & 8).
Preliminary findings showed that the ESS had arc-flashed several times, as evidenced by the burn marks and welded holes in the case, and the ESS continued to smoke long after the garage was extinguished, and the fire department was prepared to depart. After notifying the firefighters that the ESS was still smoking, they used a Thermal Imaging Camera (TIC) on the device and determined that further hose water needed to be applied to cool the ESS to prevent it from reigniting. After 15 minutes of additional water was applied to the ESS, again the TIC measured the ESS's temperature, and it was determined that the device was cool enough to release to the battery recycling crew standing by.

The crew also disassembled the ESS and noted that it had completely burned up its batteries and had no state of charge remaining at that point. Most of the EV was also consumed in the blaze, and all that remained intact was the metal shell of the vehicle and the battery case, bolted to the underneath of the frame (Figure 8).

Figure 8 (Remains of EV & Battery Pack)

One unexpected outcome of this test was that the metal garage door melted and burned down during the fire, allowing a steady stream of air to continue to fuel the blaze during the test (Figure 6). Another unexpected finding was that after inspecting the vehicle's Li-Ion battery, SMEs determined that the fire had not intruded completely through the battery case, and all battery cells were intact and had their initial state of charge. It was determined that the battery pack's position underneath the vehicle kept the battery case cool enough, being in close proximity to the garage cement floor, as to why the pack did not catch fire. It was also surmised by the battery expert on scene that the case would have failed and involved the battery cells in the fire within 10 more minutes of heat exposure, as blackened areas inside the case were evident. After a thorough investigation and analysis of the DERs involved, the batteries and case structures were disassembled, placed in crates and taken to a Li-ion battery recycling facility. Visual lesson learned and all sensor data were documented for evaluation and further analysis.

Task 1.3: Collected the Latest DER Safety Research

Reviewed and collected the latest DER literature, gathering up-to-date testing, tactics, codes, standards, regulations, and world-wide best practices to inform curriculum development.

Task Activities: Argonne and NFPA researched and collected the latest DER literature, including research papers and data shared from the Fire Protection Research Foundation, as well as from UL, who shared the results of their energy storage test fires, and their preliminary recommendations for the fire service's handling of ESS incidents (Figure 9). All collected research and data were incorporated into NFPA's training programs, animations, and simulation.

Operational Considerations For Fires Involving Residential BESS

- Pre-Plan residences in your 1st due with Solar & BESS.
- Utilize CAD premise alerts when responding to incidents.
- SLOW DOWN & conduct a complete size-up with 360°.
- Be aware of the explosive potential for any BESS.
- Due to explosive risks, avoid staging companies in the front of garages or near BESS.
- White colored smoke from a compartment containing a BESS is a good indication of hazardous off-gassing.
- Any smoke or odors from BESS are indications of a hazard.
- If a BESS is involved in a fire, ensure foam is off and apply substantial water to the battery enclosure and exposures, from a safe distance in a defensive posture.
- Never open any doors or remove any panels to BESS units
- Shutting off the battery disconnect or residential/solar power supply does **NOT** remove energy from the battery.
- Thermal imaging cameras may not be reliable identifiers of heat signatures due to BESS construction.
- The ensure foam is off absolutely if it is a traditional foam, but F500 (not a foam but encapsulator) has been successful when the cells are exposed, refer to your specific FD guidelines.
- In most residential applications, the BESS will be located inside the garage or outside on an exterior wall. IF WE KNOW OR SUSPECT A BESS IS PRESENT, STAY AWAY FROM IT. IF IT IS IN THE GARAGE DO NOT MAKE ENTRY INTO THE GARAGE. If possible, check with the homeowner on the presence and location of the BESS.

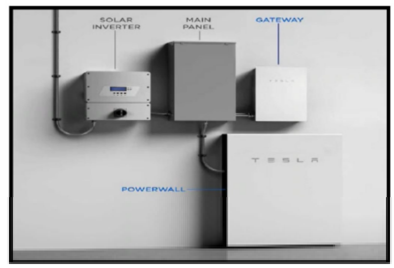

Figure 9 (Information Shared from UL's ESS Test Findings)

Task 1.4: Revised and Updated Existing Training Courses

Modularized and enhanced NFPA's classroom training with the latest DER knowledge, best practices, and tactics.

Task Activities: Following an RFP process, NFPA contracted with 'Emergency Training Solutions' to update and modularize NFPA's existing Energy Storage, Solar, and Electric Vehicle Safety Classroom Training with the latest safety information, modularizing it for the Fire Service to use more effectively. Emergency Training Solutions updated and modularized the courses into smaller chunks, allowing the fire service to more efficiently and effectively incorporate them into onboarding efforts and/or regularly scheduled training classes (Figure 10). New videos and animations were also developed to support this effort. These training modules can be downloaded by filling out a request form at www.DERSTFG.ORG .

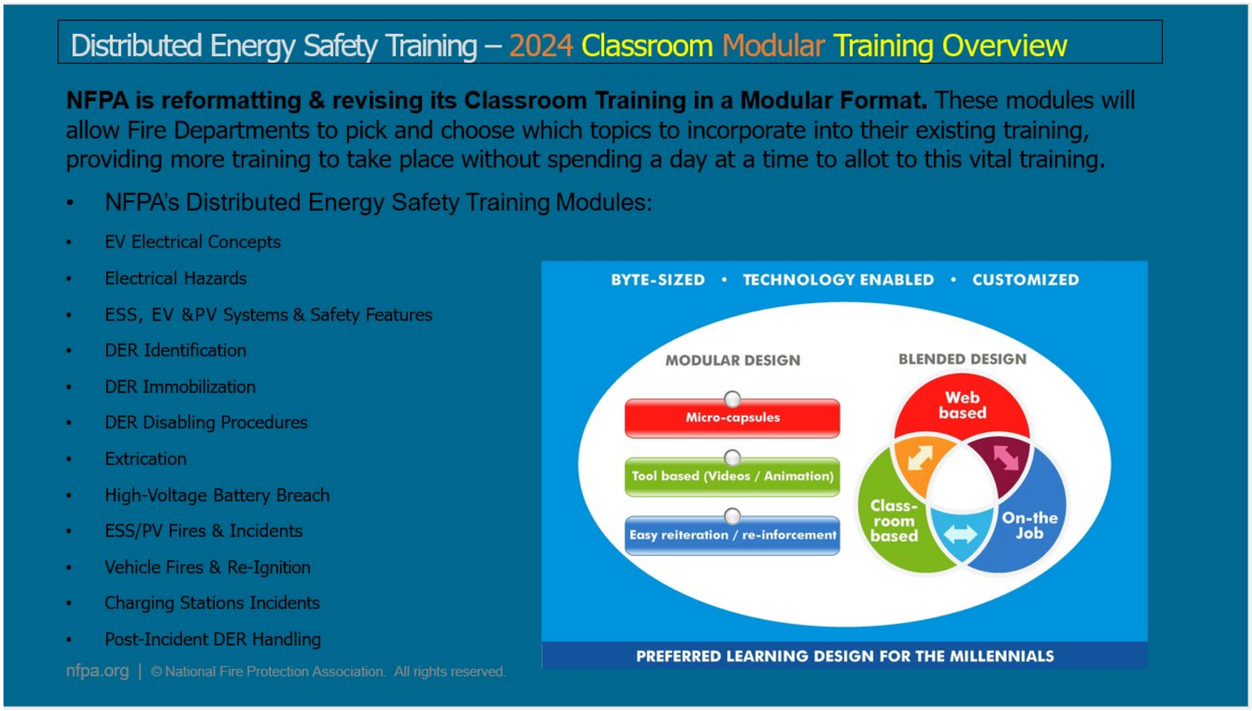

Figure 10: (DER Modularize Course Overview)

Budget Period 2 – Gaming Simulator Development & Train-the-Trainer Dissemination

Task 2.1: <u>Analyzed and Documented DER Fire Test Findings</u>

Following the completion of the DER Fire Testing, UT Austin collected and synthesized all available data received from the burn testing.

Task Activities: UT-Austin analyzed, documented, and presented their DER Fire Test Findings to this project's subject matter expert (SME) panel. NFPA's SMEs took this information and discussed, deconstructed, and analyzed the findings to identify best practices and methodologies for the fire service to respond to DER incidents more effectively. UL and IAFF had also received a copy of NFPA's best practices and methodologies for DER incidents and they recommend changes to NFPA's training. UL attended our meetings as well, and provided their lessons learned from their ongoing tests, which helped shape the learning points that were constructed (Figure 11). UT Austin submitted a full report of their DER test burn findings and analysis entitled "Acquired Structure Testing of Residential DER Equipment in a Fire Scenario", which can be found in the Appendix A. All of the information collected and analyzed has been used for input into the serious game simulation and into revisions of the DER Classroom Course modules (Task 1.4).

A. Without active fire, lithium-ion battery pack thermal runaways <u>may</u> be recognizable by white/gray battery gas leaking from the structure and forming low-hanging clouds.
B. When li-ion batteries undergo thermal runway without burning an explosion hazard begins to develop. The timing and severity of a battery gas explosion is unpredictable.
C. Significant explosion hazard can develop before any exterior indicators (visual or measurable) are shown.
D. During size-up, additional indicators for residential energy storage system installation should be considered beyond smoke appearance.
E. With an active fire, there are no reliable visual or thermal imaging indicators to confirm battery involvement from the exterior of the structure.
F. ~~Should thermal runaways occur after firefighters enter, thermal runaways can be indicated by a two-layer accumulation of whitish/gray gases near the ceiling and heavier gases and vapors along the floor.~~ Stratification of smoke at the ceiling and at the floor indicates the thermal runaway of li-ion batteries.
G. Portable gas meters are not effective for determining whether a garage fire is involves li-ion batteries.
H. Do not approach or enter to take portable gas meter measurements if there is a suspected case of batteries in thermal runaway and there are no indicators of an active fire.
I.
J. Full structural PPE with SCBA should be donned before performing size-up.
K. Firefighters are at greatest risk for explosion hazards in the driveway and at doors, windows, and other vent points. Do not park fire apparatus or stage crews in front of garage door.
L. Unburned battery gas ignites readily and can increase the flammability of the smoke in a ventilation-limited fire.
M. In all cases when li-ion thermal runaways are suspected, hose lines should be pre-deployed, charged, and ready for operations before ventilation or entry.
    - With active fire, consider creating a penetration to enable introduction of a hose stream into the garage from the exterior.
    -
N. Any time a lithium-ion battery is heat-impacted, firefighters should anticipate the potential for sudden and unpredictable thermal runaways.
    - Full PPE (including SCBA) should be worn at all times, a manned & charged hoseline should be present and an egress path should be maintained until the heat impacted units are removed from the scene.
O. If the ESS has had confirmed thermal runaways, or the ESS is suspected of being heat impacted, direct a hose stream into the ESS enclosure through any visible opening.

Figure 11 (Sample Notes & Learning Points from UL Meeting)

The following is the result of a year of NFPA's SME panel collaborating on what the final learning points should be in the Simulation Training program, based on the DER burn test in Austin, TX and UL's recommendations for ESS safety recommendations for the Fire Service.

Distributed Energy Systems Gamification Learning Points

Facts Given – Residential, one-story structure with attached garage. Garage incident. Everyone is out of the house. Call to 911 initiated.

Three Fire Departments responding with 3 trucks, team of 4 on each truck, with one being Company Officer in each truck and an Incident Commander arriving separately in an SUV. Players are 1 to 3: Incident Commander (player 1) and Company Officers (player 2 to 3). 3rd Company Officer is automated. Other Company Officers are automated or not, depending on how many players sign-in. 3 people in crew of each truck are NPCs – controlled by commands of Company Officer, who works with crew to carry out assignments. The Incident Commander moves around house doing 360 degrees size-up and then remains in front of house as orders are conveyed to Company Officers. Communications can be programmed to talk & listen over PC mic/speakers or headphones but does not need to be translated or interpreted by game into commands. One thought is commands can be conveyed by clicking on radio icon and choosing from a set of text options presented.

Three Scenarios: 1) White smoke emanating from 1 story residential garage – no visible fire

2) Garage on fire – Black smoke emanating (2 possible scenarios)

A. Fire w/o involvement of DER

B. Fire w/involvement of DER (This may be just a pop-up teaching scene instead of game scenario)

Objectives:

(Note: The decisions made by one player will affect decision trees and possibilities of other players – will need to develop flowchart)

1) **Prior to & Upon Arrival:** Identify if conditions are likely to include ESS, EV, and PV systems.
   A. From Truck, look at Satellite view for PV panels
   B. Recognize the labeling and components on the outside of structure, sounds, odors
   C. Identification of system shutdown procedures
      - Potential Actions: Scene Size-up - 360 survey of property & incident
      - Ask Owners/Residents if DERST equipment on-scene – E-bikes, propane tanks, batteries, anything considered dangerous
      - Obtain any City/Town pre-planning documents / secure adequate water supply (methods?)
      - Could you run out of H2O? Notify Utility providers to respond/standby/isolate services
      - Incident Commander provides Size-up Report over radio to dispatch. Also estimates what GPM flow is/needed.

2) Identify hazards associated with ESS, EVs and PV systems. (Tech Advisor icon provide hints w/snippets from training/including viable solutions)

A. **Explosion Hazard**

- Identify for potential for combustible gas buildup in enclosed spaces (player an observe white smoke, dark, volume, fire)
  - ➢ Potential Actions: Do not lift/cut into garage door upon arrival. (player can cut or open garage door)
  - ➢ Metering side window possibility. (player has ability to see meter registering gas – meter gets fouled – may not give accurate info – rely on all observations – not just meter)
  - ➢ Ventilation only when warranted (player can break window, cut roof or open door)

B. **Electrical Hazards**

- Recognize & Pull Electrical Disconnects (Main House Breaker, DER shutoffs) / Notify Utility Co. to disconnect power to house
- PV, EV, ESS pose shock hazards even when utility power disconnected (player sees info bubble when get too close to unit, and player dies if touches unit's exposed wires)
- ESS or EV may experience arc flash (player can observe flashes coming from equipment)
  - ➢ Potential Actions: Ask residents if DER equipment involved, avoid proximity of ESS/EV (player interacts with NPCs – word bubbles)
  - ➢ If no immediate danger/fire/gas readings detected – EV on fire, attach chain to EV and move outdoors (player can attached chain to EV and pull from garage)

C. **Fire Behavior**

- Recognition of High Voltage (Li-Ion, …) battery fires & reignition potential (word bubbles, sounds, & visual clues in pop-up video)
- Information on thermal runaway events (test data) / Overview of gases released
- Structural hazards: Obstruction to safe access to roof and wall spaces/additional dead load to roof structures (items player must address when considering roof ventilation)
  - ➢ Potential Actions: Don Full PPE – SCBA (pop-up bubble)
  - ➢ Fireground notification broadcast to all players

3. **Approach potential ESS, EVs and PV systems**

A. Obtain ERGs and Manufacturer's site for info / Preplan documents (show in training section for larger residential/commercial)

B. Protection of internal exposures (ESS, EV) and due to speed thermal runaway can progress, line placement important (player must be able to place hose-line wherever, exterior or interior of structure)

> Line placement important – may start hose line stream through side window or walk-in door before opening garage door? Correct nozzle setting important? Needs more discussion… equivalent to natural gas leak

- Fireground notification ESS/EV/PV system is involved once that is confirmed (player must be able to communicate between other players)
- Secure adequate water supply (automated function – definitely mentioned over communications to all)
- Have backup hose line - (automated function – definitely mentioned over communications to all)
- Locate dollies or chains to pull EV out of garage if warranted
- Players need to be able to enter both the house and the attached garage as an option
- Notification of utility providers to respond/standby/isolate their service into structure (Player needs to be prompted as option during decision making process)
- If EV is exposure/creating hazard, prioritize moving vehicle (internal exposure)
- Keep the hose line on EV (dedicated line) & pull EV out when safe to do so.

4. Post Incident

- Potential Action: Checking DER Systems' status (TIC, Responsibility of Property Owner to contact qualified technician) (Player has ability to use and visualize the screen of a thermal imaging camera)
- Assess DERs – see, smell, hear, TIC, guidebooks, evaluate temp for chance of reignition
- Potential Action: Pull EV out of garage if perpetuating fire / considered exposure.
- Use thermal Imaging Cameras (TICs) to confirm falling temp of DERs and if low enough to transport.
- Reignition Hazard - Continued water application for cooling DERs (Player has ability to use hose lines wherever)
- Effective handoff to Tow/Salvage or Homeowner – make aware of next steps/remaining hazards.
- Cleaning of equipment and PPE Decontamination (pop up bubble after game complete)
- Before clearing scene, meet with responsible party and provide what to watch for indicating reignition/continued off gassing (word bubble)

Overhaul – use tools to open walls and flood them / clean area / remove window frames / roof may need to be removed

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Task 2.2: Dissemination of Classroom Training Materials

DER safety classroom coursework was advertised and propagated across the country by NAFTD to all state and local fire training academies.

Task Activities: In order to distribute the classroom materials in an expediated manner, distribution planning meetings were held with the North American Fire Training Directors (NAFTD), who held a webinar in January 2024 to advertise and display our classroom modules to the fire training directors and officers. NAFTD also advertised this training to their members at their annual conference, and began distribution of the classroom training materials nationwide, and made it possible to request the materials online at https://derstfg.org/download-training-request/ (Figure 12).

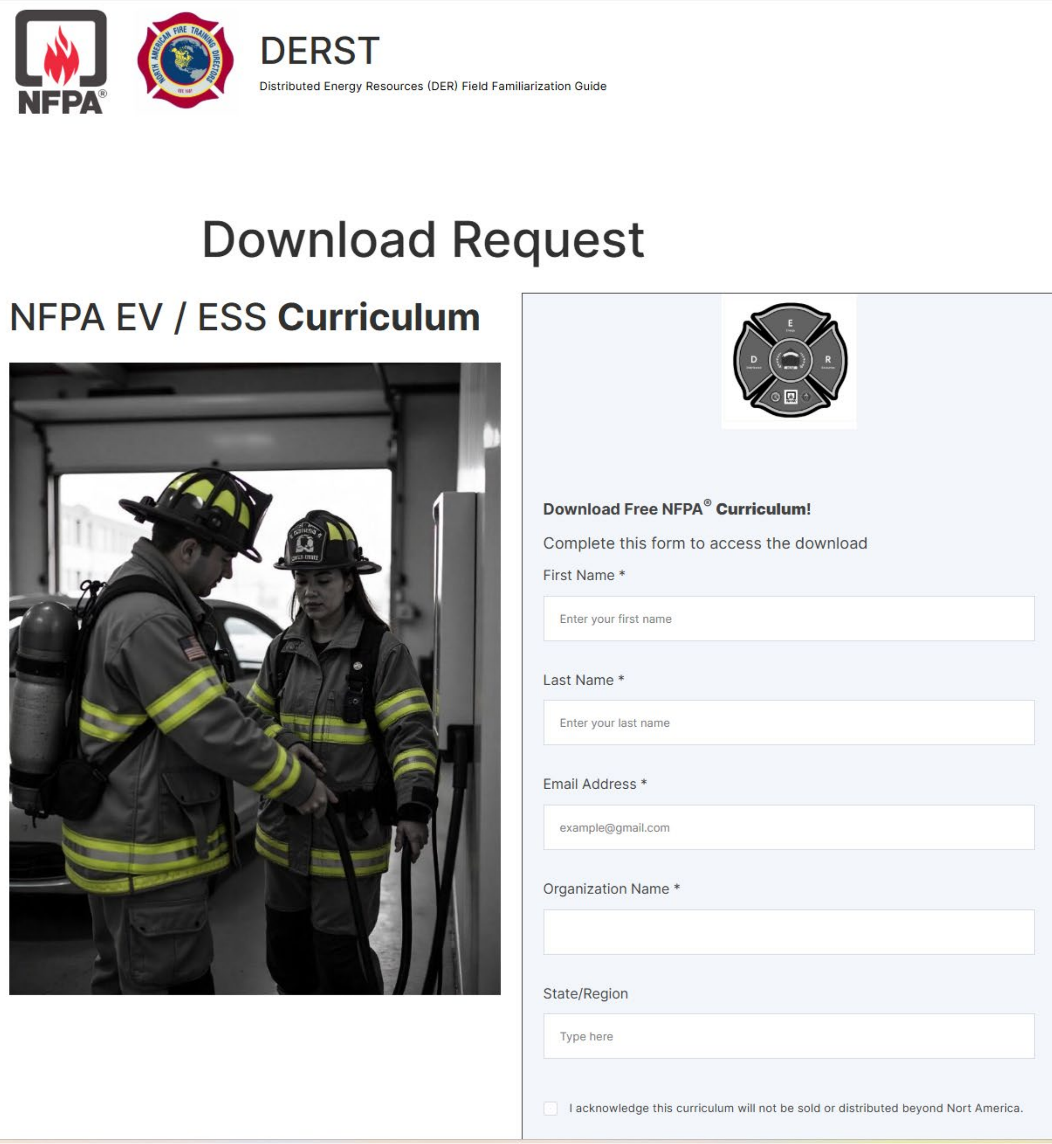

Figure 12 (Download Request Site for U.S. Fire Service for DERST Classroom Training)

Task 2.3: Onboarding of Serious Gaming Development Vendors

A request for proposals was issued for a qualified eLearning/instructional design and development vendor. GHD Digital was chosen and contracted with.

Task Activities: NFPA constructed an RFP and gamification flowchart and distributed to 4 computer gaming organizations. The vendor that was chosen was GHD Digital, who had experience creating fire service gamification for multiple player interactions in a realistic setting. They employed the Unreal 5.0 engine for their graphics environment and claimed they were capable of recreating our Austin TX single story residential structure for the virtual environment using a high resolution, realistic graphics setting, which NFPA learned from other graphics projects that the fire service has come to expect. Game play would be free form and involve an incident commander and multiple fire departments responding to a DER incident.

Task 2.4: Development of Serious Gaming DER Safety Simulator

GHD Digital, NFPA, the project's SMEs, and NAFTD, conceptualized and developed a multi-player, multi-role, multi-venue, multi-interconnected-DER incident gamified simulation training tool called FIRST (Firefighters Incident Response Simulation Tool).

Task Activities: Specifications and flowcharts were provided to GHD Digital, who mapped the flow of the serious game and constructed the interface. DOE had asked us to work with UL and incorporate their ESS fire testing into our training. UL had requested to DOE that NFPA's project be extended 7 months to give adequate time for UL's Energy Storage Safety testing to be complete (on a parallel DOE grant, where UL's findings were to be distributed by NFPA to the fire service) to make the game as realistic as possible, and to provide the absolute latest safety best practices for the fire service. DOE approved the request, extending NFPA's overall project timeline to December 2024.

GHD Digital reviewed the provided course materials (e.g., classroom course materials, online training modules, videos, & images) and DER research (e.g., research reports, fire test data, computer simulations, & fire testing footage) and provided instructional analysis, audience profiles, and a strategy for developing an engaging, gamified learning experience. They then identified the learning objectives, design challenges, stakeholder requirements, and specifics regarding recommended instructional formats/methodologies for program components, to include scenario-based learning, gamified interactions, immersive experiences, user feedback, and other training development methods to ensure learner engagement and comprehension.

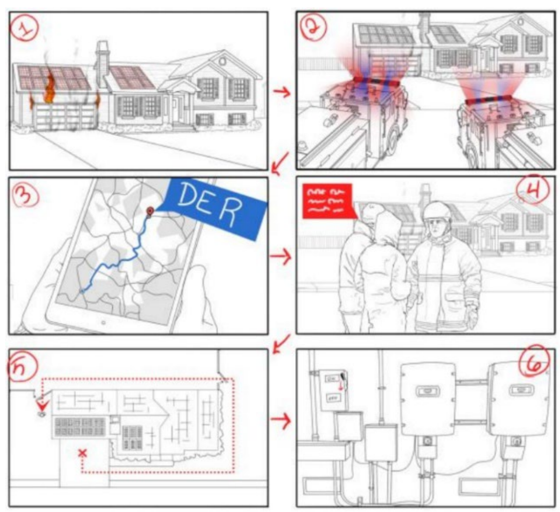

Figure 13 (FIRST Storyboard)

GHD Digital developed detailed curriculum outlines, storyboards (Figure 13), and scripts for gamified content, addressing the learning needs of the identified audience using 3D animations, simulations, and other advanced graphic design elements.

NFPA provided GHD Digital with draft specifications for development of the serious game. These included:

- Gamified real-world environments utilizing 3D modeling or other similar high-engagement, high resolution platforms.
- Simulated emergency incidents including smoke, fire, explosions, and other events fire fighters may encounter during a structure fire.

- A nonlinear instructional design approach that uses real-time game branching to challenge the user's comprehension, thus allowing for many possible performance outcomes during serious game play.
- A multi-user interface allowing for up to 5 simultaneous users filling individual roles to tackle the challenges as a team.
- In-program leaderboard and performance metrics for real-time assessment and feedback on performance.
- A multi-user interface that provides a desktop and mobile-friendly platform with detailed progress tracking.

The resulting FIRST simulation training was very well received by the emergency responder segment, the media, and NFPA's DER stakeholders (Figure 14).

Figure 14 (FIRST Simulation for Interactive DER Firefighter Training)

Task 2.5: Comprehensive Review of Gaming Simulator

Upon completion, the Serious Gaming DER Safety Simulator was evaluated from a scientific, technical, and responder tactics standpoint during a multi-tiered beta review process prior to delivery. Firefighters from various departments participated in the tests.

Task Activities: The DERST serious game simulation was tested by selected fire departments in both Connecticut and Massachusetts for feedback. The game has been updated twice in the third quarter of 2023 to incorporate their feedback and revised to support section 508 compliance to ensure that the simulation was accessible to people with disabilities, and the program was signed off by NFPA as completed and released. NFPA and Vector Solutions together sent a media advisory announcing that Vector Solutions has the ability to place the FIRST Simulation application on any state academy FVector LMS, and this message was distributed to all NAFTD members as well. NFPA established a link to the Simulation program and training on their website and now directs all organizations wanting to host the DER Training and Simulator to the DERSTFG.ORG portal. NFPA also made this training more accessible for individual responder participants, so it is available on NFPA's EV landing page (www.NFPA.org/EV), the Vector Solutions platforms (https://info.vectorsolutions.com/vs-fr-nfpa-new-energy-systems-fire-simulator-training), on the www.DERSTFG.ORG platform and directly from NAFTD.

Budget Period 3 - DER Field Evolution Software, DER Prop Guide Development & Public Relations

Task 3.1: Field Familiarization Evolution Software and Props Guide Development

Conceptualized, designed, and developed a unique web guide to field familiarization evolutions activities and a DER prop selection guide that aids departments holding DER familiarization exercises on-site at DER locations and setting up outdoor field evolutions at fire academies and department training centers.

Task Activities: As more Distributed Energy Resources (DER) are deployed across our nation, the fire service is challenged to stay abreast of the latest best practices and tactics surrounding these new technologies, as well as to track the installation of DERs within their response area. A key method the fire service uses to digest information learned during training and apply it to the physical infrastructure within their response area is to perform walk-through familiarization exercises as a team. Typically, this activity will see one or more fire companies visit a local "target hazard" DER, under the supervision of a fire officer while touring the site. This activity takes place after the firefighters have completed the DERST training programs as a prerequisite, which were developed and released in previous phases of this project (Figure 15).

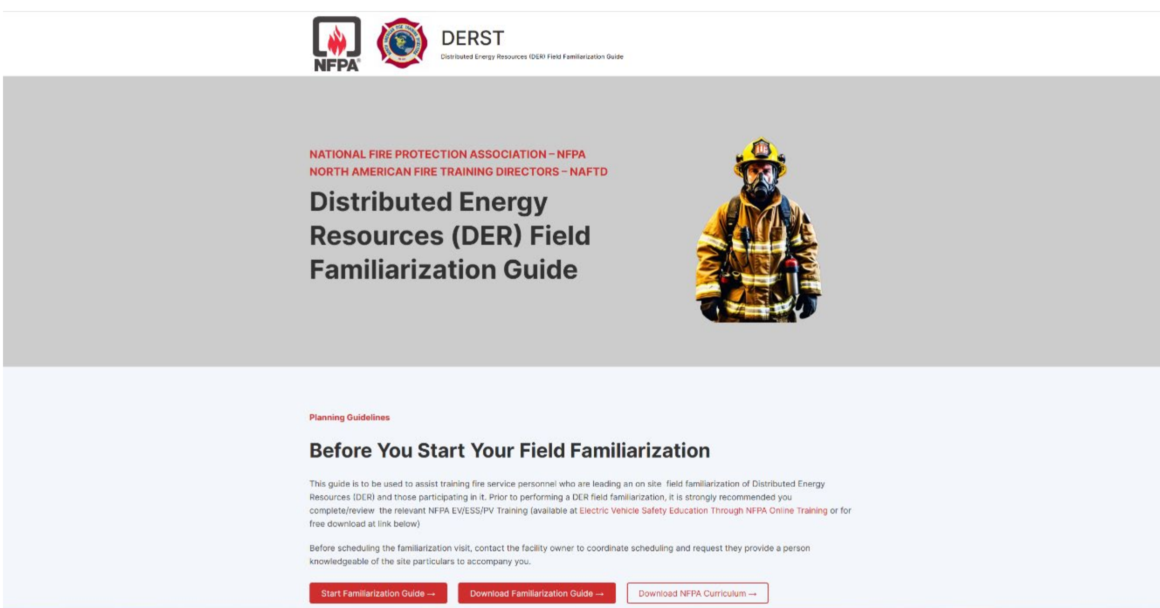

Figure 15 (Field Familiarization Evolution Opening Screen)

Figure 16 (DERST Field Evolutions Menu)

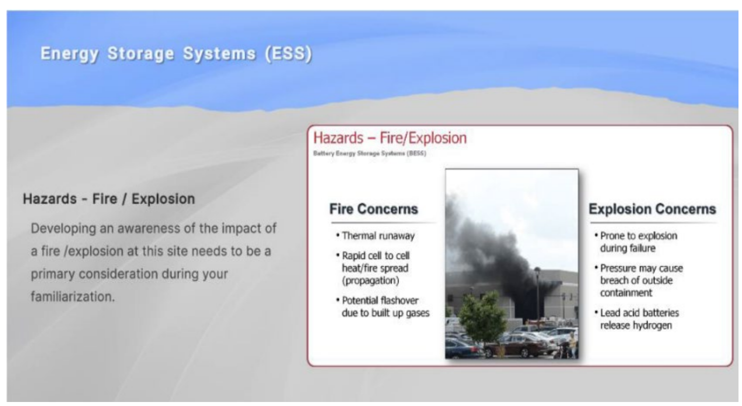

Figure 17 (Field Guide on ESS Hazards)

The final phase of this project addressed these Field Familiarization Exercises, where the North American Fire Training Directors (NAFTD) developed, tested, and released NFPA's Field Familiarization Evolution Program (Figure 16). This Field Evolution program provides the U.S. Fire Service opportunities to conduct live, on-scene training exercises at local DER installations of Battery Energy Storage Systems, Solar Panel Farms, Lithium-ion battery and electric vehicle storage areas and/or demonstration centers. Responders use their smart devices to access the DERST field guide familiarization software to run through component identification, potential hazard situations, and team incident scenario discussions to better prepare for potential future DER events (Figure 17). To better support firefighters during these field familiarization exercises, this online guide acts as an engaging and responsive, interactive experience that can be accessed via web browsers on various laptops and mobile devices, which provide guidance, scenario training and verbal field exercises to fire service personnel to sharpen logistic and reasoning abilities prior to being called to incidents. Drawing on their knowledge obtained from their previous DERST training and simulation exercises, they can now face virtual hazard scenarios as a team on their smart devices, while performing a field familiarization evolution of a DER facility.

This Field Evolution Guide presents the summarized safety elements from NFPA's DERST training programs and a high-level overview of the safety and testing standards incorporated into DERST installations, and against those criteria, allows the participants, as a team, to apply the characteristics of a specific facility, utilizing potential hazardous scenario incidents to better prepare our responders for several emergency situations (Figure 18). These activities will enhance understanding by our firefighters, promote discussion and mental exercises of how to combat incidents involving these technologies, and prepare them for action during real world incidents.

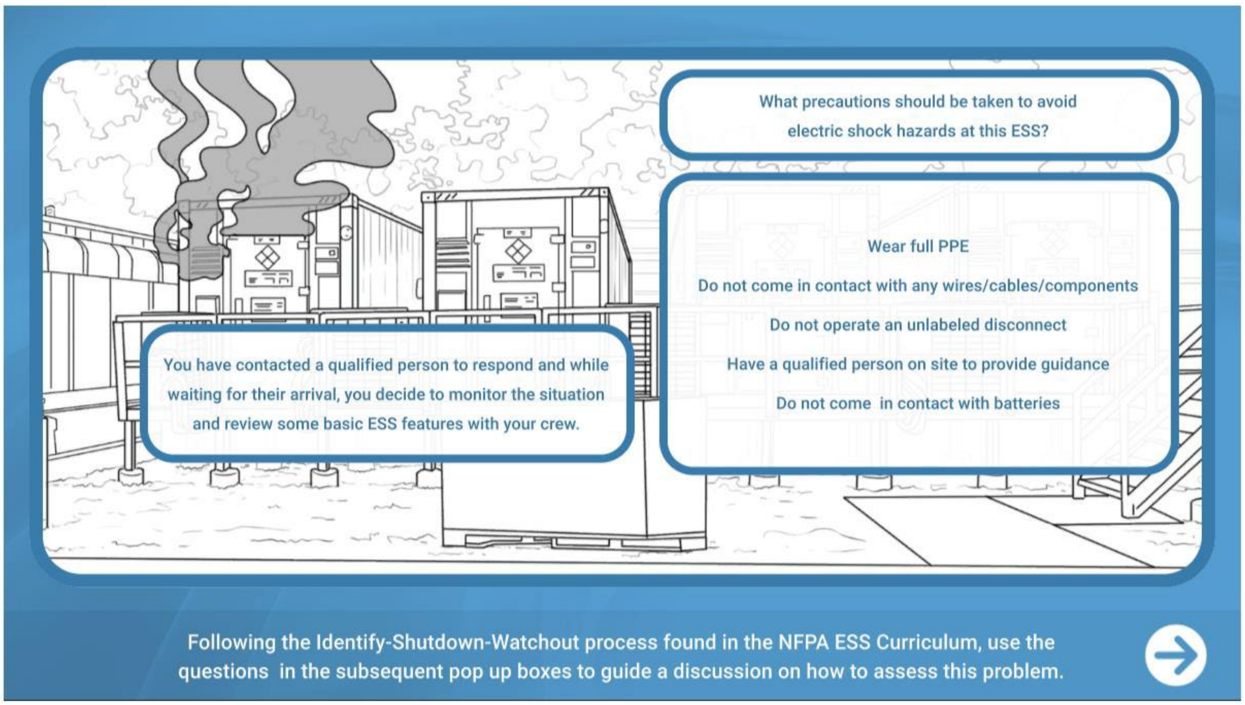

Figure 18 (Field Evolution Collaborative On-site Exercise)

To ensure ease of use by the fire service, this software utilizes the Unity 2d framework, allowing an interactive menu system, animations, and visual effects to be used where needed to supplement discussion amongst peers and their training officer. Access to this DERST Field Familiarization Evolution Program is accessible, free of charge, to the fire service and the responder community at large through NAFTD (website: www.DERSTFG.org).

Also completed and accessible from the DERSTFG.org website is a DERST Field Evolution Prop Development booklet providing guidance for DERST systems prop construction for field evolution training (Figure 19). These props will simulate energy storage devices, electric vehicles, charging stations, solar panel arrays, and other lithium-ion devices, which can potentially also provide simulated smoke and fire scenarios to be created for real-world training exercises. Commercial manufacturers and OEMs can use this manual as guidance on how to construct props for firefighters to train on their training grounds, learning firsthand in the field how to respond effectively to DER incidents without causing damage to the battery systems, circuitry, and fire scenarios, which could result in thermal runaway or putting themselves in danger of spraying water too closely on an ESS, for example, and having energy jump back through the hose stream. The development of these props from this guide will provide safe exposure to real-world technology simulations without the risk of experiential learning and enduring battle scars (Task 3.1).

Guidance for Development of DERST Training Props

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Figure 19 (DERST Training Prop Outline)

Task 3.2: Field Evolution Activities and Props Guide Dissemination

NFPA, NAFTD, and Vector Solutions nationally advertised the field familiarization activities software and hosted the software on a web portal available to the U.S. Fire Service free of charge.

Task Activities: NFPA's Communications Division worked with Vector Solutions and NAFTD to assemble a press release, social media posts, and email blasts to alert the U.S. Fire Service that the Field Familiarization Evolutions Training was ready for use (Figure 20). NAFTD setup a web portal where the DERSTFG software guide and DER Props Guide, as well as all of the training delivered as part of this grant are hosted for all U.S. emergency responders.

NFPA **NEWS RELEASE**

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For immediate release

NFPA, U.S. Department of Energy, and Vector Solutions team up with North American Fire Training Directors (NAFTD) to guide U.S. fire departments in effectively mitigating fires that involve distributed energy resources (DER)

Last year, the National Fire Protection Association® (NFPA®) and Vector Solutions launched a program to properly train U.S. fire departments in safely mitigating fires that involve energy storage technologies (such as battery energy storage systems). While the first part of that effort focused on classroom training materials and an interactive, game-like simulated training for responding to battery energy storage and electric vehicle fires, the second phase of the series, officially being launched by NFPA, Vector Solutions, and the U.S. Department of Energy, in coordination with the North American Fire Training Directors (NAFTD), addresses mitigation training for a field evolutions approach of distributed energy resources (DER).

"As more distributed energy resources are deployed nationwide, the fire service needs to be properly prepared to respond to them safely and effectively," said Andrew Klock, senior manager of education and development at NFPA. "This second phase of field-based familiarization trainings provides firefighters with the skills and know-how to address a wide range of installations, including battery energy storage systems, solar panel farms, lithium-ion battery and electric vehicle storage areas and/or demonstration centers."

The newly launched DER training features field familiarization exercises that enable fire departments to apply the information they've learned in previous trainings and during on-site walkthroughs held at "target hazard" locations. In addition, to better support firefighters during these exercises, an online guide acts as an engaging, responsive, and interactive experience, providing guidance, scenario training, and verbal field exercises that help sharpen logistic and reasoning abilities on-scene.

"Drawing on their knowledge obtained from prerequisite online and classroom training and simulation exercises, firefighters can now face virtual hazard scenarios as a team on their smart devices, while performing a field familiarization evolution of a DER facility," said Klock.

Figure 20 (Press Release for the Fire Service Field Evolutions Software Training Program)

Results & Impact

The objectives of this project -- to research, develop, and deploy a suite of DER educational programs and tools for emergency responders surrounding incidents involving battery energy storage systems (ESS), solar/photovoltaic (PV) systems, electric vehicles (EVs), their charging infrastructure (EVSE), and other lithium-ion (Li-Ion) battery-based devices were achieved. Firefighters, first responders, public safety officials, and other relevant emergency response professionals nationwide now have access to 1) revised best practices and tactics when responding to DER incidents; 2) updated and modularized DER classroom safety training programs for the fire service and emergency responders on handling ESS, PV, and EV/EVSE incidents; 3) a multi-user and multi-role, scenario-based serious DER simulation gaming platform for fire departments (FIRST app); 4) a field familiarization evolutions web program providing responders enhanced safety learnings during a live collaboration training experience with DERs during field evolutions; 5) a DER Prop Guide for safety instruction and design guidance when constructing and deploying props at any DER live training facility; 6) and a convenient web portal that provides easy access to all these safety tools and programs.

NFPA, Vector Solutions, and NHTSA have run PR campaigns with press releases, social media posts, and email blasts to promote the availability of the training modules, FIRST simulator, and field evolutions web guide as they were deployed. NAFTD also held webinars and demos of the training programs to their membership multiple times, which spurred increased interest in hosting the FIRST application and downloading the training. In response to the availability of these new offerings, many organizations have also hosting the FIRST simulation training, such as Texas A&M Engineering Extension Service (TEEX), the Emergency Training Institute (ESTI), the North Carolina Fire & Rescue Services, the Delaware Fire School and the Quincy MA Fire Department (Figure 21). It is estimated by NAFTD that approximately 5000 fire departments across the country have downloaded the modular DER coursework, and within 7 months of its release, over 1,100 Departments and Firefighters have downloaded the FIRST simulation app. A revised effort to promote the FIRST app occurred recently by NFPA and Vector Solutions, both on social media and press releases, should drive these numbers even higher in the year ahead.

During 2024, NFPA fielded many questions from the media and took 37 interviews about DER incidents from varied publications and from CBS, NBC, ABC, CNN, Bloomberg, the Weather Channel, and the New York Times. NFPA presented the FIRST application and DER Safety Training at the MATOC (Metropolitan Area Transportation Operations Coordination) Regional Traffic Incident Management Symposium, which hosted over 150 East Coast responders on the FIRST program. This demonstration was provided to the Fire Service, Law Enforcement, Tow & Salvage, and various state Department of Transportation officials and the interest was substantial. We expect the downloads of all these deliverables to continue through 2025 as DERs continue to become more prevalent in the U.S.

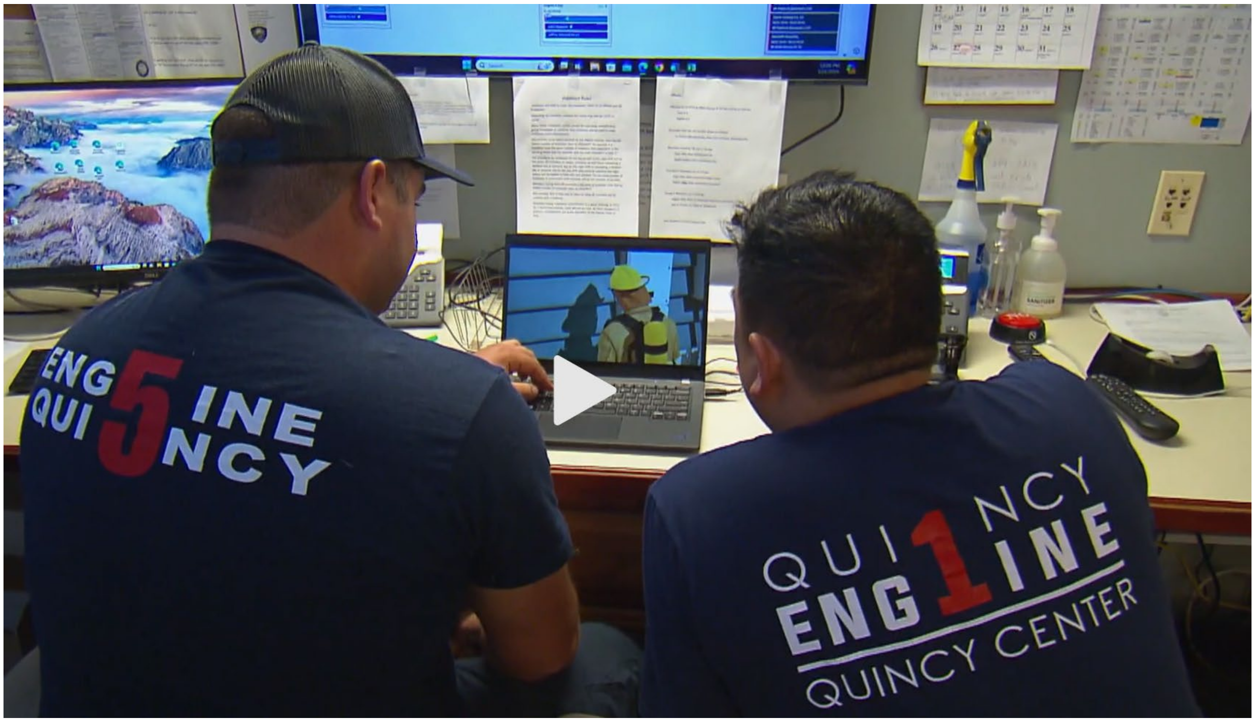


Figure 21 (Quincy MA Firefighters using the DER FIRST Simulation Program)

An exciting development centered on DOE providing the opportunity for NFPA to film a nationally run PBS MotorWeek segment on the FIRST application, which aired Nationally in June of 2024. The program highlighted NFPA's efforts on DER and EV safety and provided widespread PR about the FIRST program and how vital it is for the first responder communities across the country. This effort has continued to spur interest in the program, where current statistics show over 100 new participants a week since its airing (Culmination of Task 2). The segment can be found at https://www.pbs.org/video/2024-drivers-choice-awards-ord5uw - 7 minutes in (Figure 22).

Figure 22 (MotorWeek Segment on DER FIRST Simulation)

One of the most impactful parts of this grant is what was learned about handling DERs during a fire and/or incident. 1) the Fire Service's standard practice across the country when responding to a garage fire is to bring a hose to the garage door, open or cut through the door and hose down the inside. We have learned that with DERs possibly present in the garage, including an ESS or EV, this mindset could be dangerous or ever deadly. Distressed lithium-ion batteries will off-gas, and these flammable gases can build up in the garage cavity. With the introduction of oxygen to the environment, such as opening the door or turning on an uncharged hose, this can cause a significant explosion, expelling a garage door across the driveway and potentially across the street, as we seen happen multiple times (Canada, Arizona, and Colorado). It took a couple months for NFPA's SMEs to discuss and accept a new paradigm shift for firefighters responding to the scene of a garage fire – if there is smoke, especially white smoke emanating from the garage door, or if you suspect a DER inside, you should not go near the garage or the driveway, or park any apparatus in the driveway, since an explosion may be imminent. This learning point was captured in NFPA's FIRST simulator, as is shown in Figure 23 and 24.

Figure 23 (DERs inside garage and white smoke emanating)

Figure 24 (Possible consequence of opening the garage door)

Many additional learning points were arrived at from the data captured at the burn test scene in Austin Texas, from shutting off the solar PV emergency disconnects first to approaching the DERs from a 45 degree angle, to avoid a direct explosion, gas jet flame from a puncture, or shrapnel shooting out of the device. When the fire was roaring, many pops and cracks were heard, and it was later realized that the ESS was arc flashing. Arc flashing is a dangerous electrical event where a high-voltage electric current jumps through the air from one conductor to another or to ground, creating an intense burst of energy. This sudden release produces extreme heat, light, sound, and pressure—which can result in serious injury or death. Temperatures can exceed 35,000°F—hotter than the surface of the sun, and the blast force can knock workers off their feet and send shrapnel flying. The intense light (ultraviolet and infrared) associated with these flashes can also cause temporary or permanent vision damage and the sound pressure may exceed 160 dB, potentially rupturing eardrums. It was deemed best to avoid approaching ESS DERs that are burning and to spray them with water from a distance.

Another important learning point was arrived at when, after the test fire was extinguished and deemed safe by the fire department, the ESS continued to smoke. After using a TIC to determine its temperature was too high and it was in danger of reigniting, the fire department decided to unravel their hoses and continue to spray the device for an additional 15 minutes, until the TIC measured a safe internal temperature (Figure 25). This was a very important lesson for the Austin fire department to learn, and consequently for the rest of the country as well. When DERs are involved in the fire, post event cooling and temperature monitoring of all DER devices must take place. Even though the blaze may be out and the scene considered safe, lithium-ion batteries, when damaged, generate their own heat and oxygen and if still hot, can reignite at any time. An additional lesson that was conveyed in the FIRST simulation is that to minimize the risk of reignition, any DERs that had been involved in a fire that has been extinguished must be moved out of the structure. The fire service removed the EV and ESS from the garage, which prevents the device reigniting the structure over and over (Figure 26). The last lesson that will be mentioned here, is that even opening a small side or back door to a garage or room with an ESS involved in a fire may result in an explosion as well, or a flashover when oxygen is introduced. The FIRST simulator allows the firefighter to open the door only wide enough to spray water into the garage. If the door is opened too quickly, the fire will rapidly expand (Figure 27). All the additional learning points agreed upon from the burn test and UL's ESS tests are outlined above in Task 2.1. As described, the benefits and lessons learned and conveyed to the U.S. Fire Service because of this grant are many and the prevention of injury and lives saved will result from trainings, simulations and tools produced.

Figure 25 (Firefighters lowering the temp of ESS)

Figure 26 (FIRST simulation allows winch to remove EV before EV reignites structure)

Figure 27 (Firefighter opening garage back door too wide expands the fire rapidly)

Appendices

Appendix A: UT-Austin Analysis of DER Fire Test Report

Acquired Structure Testing of Residential DER Equipment in a Fire Scenario

Kate Pinkerton, Erik Archibald, Sam Matthews, Andrew Klock, and Ofodike Ezekoye

ABSTRACT

There is relatively little characterization of the fire evolution associated with the failure of lithium-ion powered devices in residential occupancies. Understanding this evolution will be useful for engineering smoke and fire mitigation systems as well as detection and alarm systems. For the fire service, it will be useful to better understand the rate at which these fires grow as well as the utility of firefighter HAZMAT gas sensors in characterizing the environment as cells fail.

In April 2022 testing was conducted by UT Fire Research Group in partnership with the NFPA and Austin Fire Department with the goal of characterizing the fire spread process in a residential garage containing various types of lithium-ion battery systems. In this test, we initiated a fire growth and spread process initiated by and consuming significant quantities of lithium-ion cells. The garage was instrumented to measure temperature, heat flux, and gas evolution.

INTRODUCTION

Lithium-ion batteries have become the leading secondary (rechargeable) cell types used in a variety of portable electronics devices, electrical mobility systems, and stationary energy storage systems. This technology continues to gain use cases due to its high energy and power densities, long cycle life, and low self-discharge rates. Lithium-ion batteries are defined in terms of their form factors and the cathode chemistries. The notable form factors are cylindrical, pouch, and prismatic formats. In all cell formats, the cell comprises various layers of materials forming the electrochemical system. The repeating layers are generally an aluminum film current collector on which a cathode layer has been deposited. The cathode layer chemistries are typically a metal oxide that includes lithium. Typical cathode chemistries include lithium-cobalt-oxides, lithium-nickel-cobalt-aluminum-oxide, lithium-iron-phosphate, and various lithium-nickel-manganese-cobalt-oxide systems.

Lithium-ion cells and associated battery technologies are generally quite safe, but under some abnormal conditions, a high temperature failure event occurs. Thermal runaway is a thermal event that occurs in cells and batteries that is characterized by internal exothermic reactions that overwhelm heat loss from the system and result in increasing cell and battery temperatures. Thermal runaway can be induced in a cell by one of several abuse scenarios: manufacturing defects, electrical abuse, mechanical abuse, and thermal abuse Larsson et al. (2016), all of which ultimately result in damage to the separator, causing an internal short circuit that increases temperatures within the cell. With the increasing use of this technology, there have been well documented accidents (fires and explosions) that have occurred as a result of cell failures with a list of known incidents. To the knowledge of the authors, there is no characterization of the fire evolution associated with the failure of lithium-ion powered devices in residential occupancies. Understanding this evolution will be useful in a variety of applications, such as engineering fire mitigation, detection, and alarm systems. Additionally, battery manufacturers can better design modules and packaging to prevent failure due to external heating. For the fire service, it will be useful to better understand the rate at which these fires grow and the optimal method to extinguish these fires.

In April 2022 testing was conducted by UT Fire Research Group in partnership with the NFPA and Austin Fire Department with the goal of characterizing the fire spread process in a residential garage in Austin TX, where the structure was purposely lit on fire in the garage by overcharging a battery electric drill.

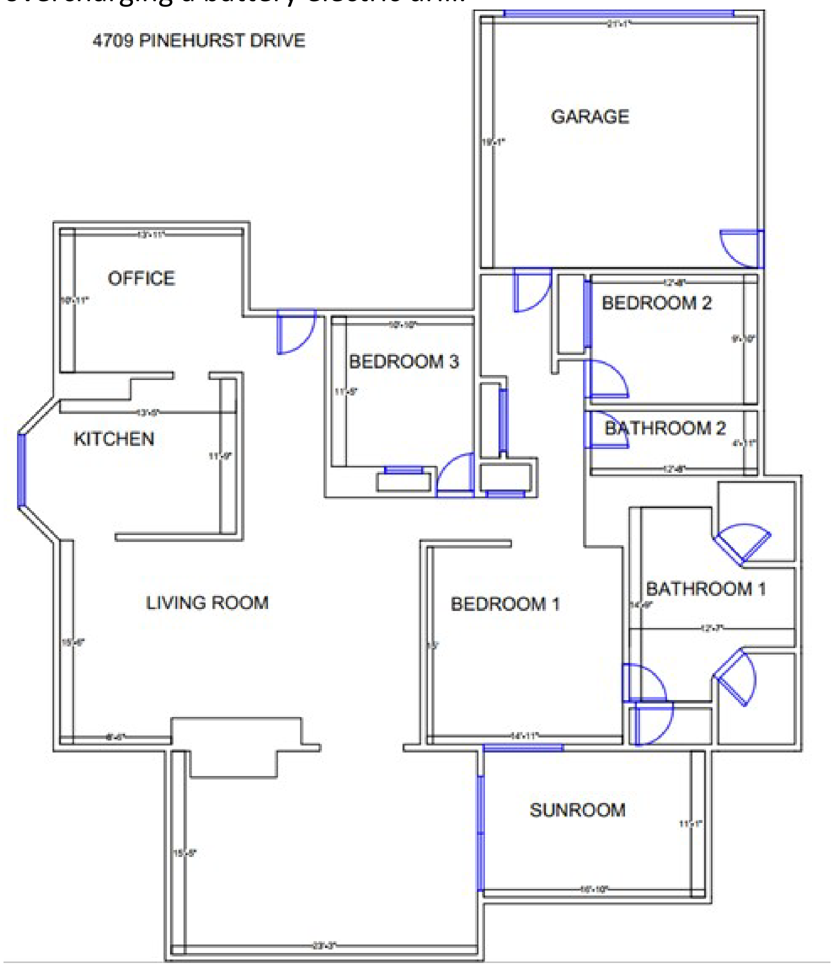


Figure 1. Layout of Pinehurst house. Garage is seen in top right corner.

containing various types of lithium-ion battery systems. In this test, we initiated a fire growth and spread process initiated by a single 18650 cell. Numerous lithium-ion cells and standard combustible items were consumed. Temperature, heat flux, and gas concentration data were collected.

EXPERIMENTAL SETUP

Two tests were conducted in the garage of a single-level house to study the thermal hazards generated by distributed energy resources (DERs). Fire service partners (Austin Fire

Department) were present and prevented the fire from spreading to the attic and to the remainder of the house. The garage was fire-hardened by lining the walls and ceilings with additional layers of gypsum (two layers, each 0.0125 m thick). Figure 1 shows a schematic of the house used for burns. Figure 2 shows the location of the thermocouple trees, individual thermocouples, and DFTs in the garage. Additional ventilation paths (approximately 30.5 cm x 30.5 cm) were cut in the garage door and a side entry door. The locations of doors and ventilation paths are indicated in Figure 2. The garage contained ordinary fuels in addition to numerous lithium-ion batteries.

Fuels

In the second test, several fuel packages were present in the garage (Figure 3). Three 20-Wh NMC drill batteries were placed in two trashcans with paper combustibles (Figure 4). Adjacent to one of the drill batteries was a hoverboard with a 160-Wh NMC battery. 9 cartons of unexpanded group A plastic commodities containing polystyrene cups divided in corrugated cardboard boxes were arranged between batteries in addition to a wood pallet. A 10-kWh LFP energy storage system (ESS) was mounted to the garage wall.

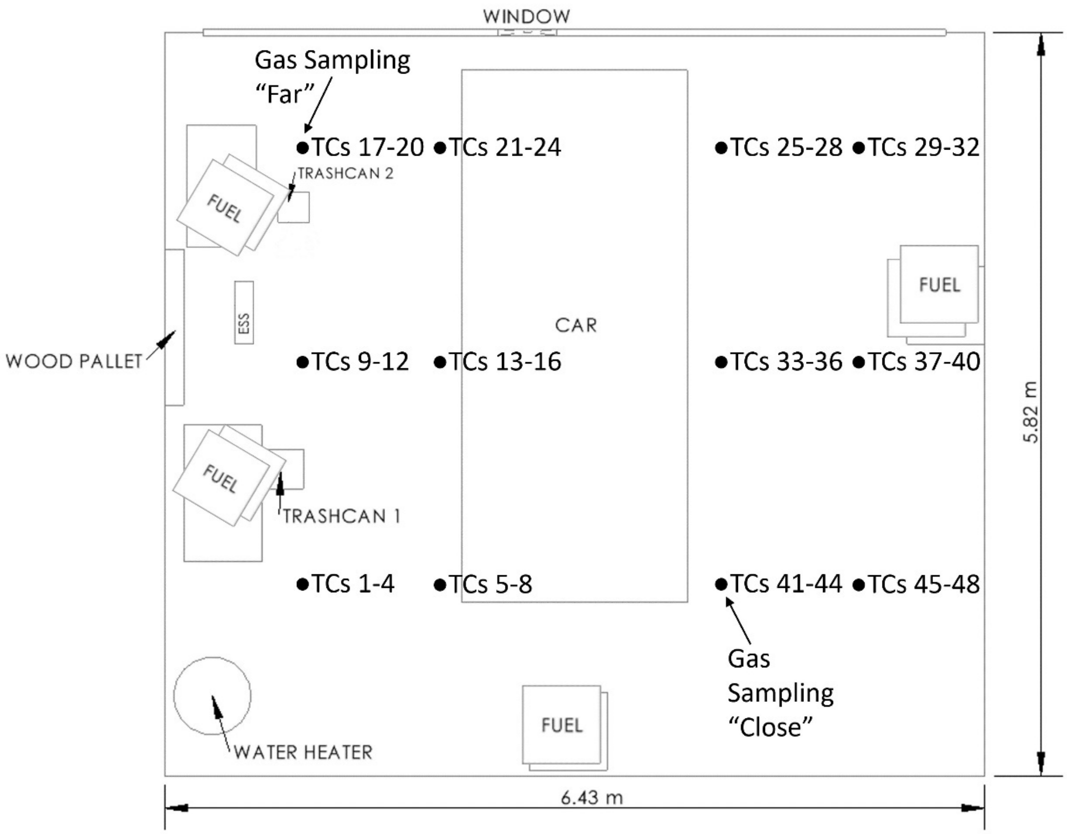


Figure 2. Grid thermocouples and gas sampling locations in the garage. The garage door is at the top of the schematic and the rest of the house is at the bottom of the schematic. "Fuel" refers to the cardboard box fuel loads.

Figure 3. Test fuel configuration. The EV is seen on the right. On the left wall are the BESS, along with several standard combustible items. The three drill batteries in two wastepaper baskets and the hoverboard are on the floor of the garage between the EV and the left wall.

wall. An electric vehicle with a 66-kWh NMC 622 battery was in the center of the garage. All batteries except for the EV battery were tested at 100% state of charge (SOC). The EV battery was at 30% SOC.

Environmental Measurements/Sensors Deployed

Temperature Measurements

Temperature measurements were made using 82 thermocouples. Thermocouples were placed at 12 locations throughout the garage at heights of 2.44 m (8 ft), 2.13 m (7 ft), 1.63 m (5.3 ft), and 0.61 m (2 ft). Additional thermocouples were placed at locations of interest on and inside the DERs. Thermocouple locations are detailed in Figure 2. The thermocouples used for measurements were 24-gauge, Type-K thermocouples with fiberglass insulation. The thermocouple wires were drawn out of the house through the bedroom window and small holes in the garage doors into three Graphtec GL840's. The data sampled at a 1 second interval and saved on the Graphtecs' SD cards.

Heat Flux Measurements

Directional flame thermometers (DFTs) were placed throughout the garage to record heat flux signatures as the fire evolved Cabrera et al. (2020). DFT locations can be found Figure 2. Figure 5 shows an example of placement of two DFTs on the BESS.

Gas Measurements

Concentrations of O_2, CO_2, and CH_4 were measured from several sensor modalities packaged in-house. O_2, LEL, CO, and H_2S concentrations were also collected via an Altair 4XR, a commonly used firefighter multi-gas sensor. Several MultiRAEs were deployed in the surrounding area, but they did not detect any gases. Gas sampling locations are shown in Figure 2.

Figure 4. Drill battery setup. Two orange wires are heater power. Tan wire is thermocouple. A hole was drilled in the cell to provide access for a micro-heater and thermocouple.

Figure 5. Two directional flame thermometers (DFTs) positioned on the bottom and corner of the battery energy storage system (BESS).

(a) Firefighters applying water to the battery energy **(b)** Battery energy storage system
post-test. storage system.
Figure 6. Extinguishing and disposal of battery energy storage system.

Visual Observations
Five security cameras were deployed in the back two corners of the garage, in the attic, outside of the door from the garage to the side yard, and in the hallway connecting the house to the garage. Aerial footage was collected from drones above the house. Additional footage and photos were captured using mobile phones. Thermal cameras were deployed outside of the garage but were destroyed due to exposure to high temperatures.

Procedure
To initiate the test, we inserted a thermocouple and micro cartridge heater into an 18650 cell which was then inserted into a power drill battery with other fully charged 18650 cells Yan et al. (2022). The drill battery pack was then “improperly discarded” into a wastepaper basket with paper and ordinary combustibles. The cell was heated to $200^{\circ}C$ to induce thermal runaway. The fire department applied water to roof and garage door of the garage throughout the test to prevent the fire from spreading to the rest of the house or attic. After approximately 1 hour, the fire was extinguished with water. The electric vehicle and battery energy storage system were removed from the garage and extinguished individually with water, as seen in figure 6a and figure 6b.

RESULTS AND DISCUSSION

Pictures/Visual Observations

The first cell in the drill battery was heated to initiate thermal runaway. In the security footage, the cell can be heard venting, before igniting (Figure 7a & 7b). The resulting fire consumed the paper in the first trashcan (Figure 7c) and spread to the two cardboard boxes above the trashcan (Figure 8a). The flaming material fell from the shelf above, dropping onto the hoverboard beside the first drill battery (Figure 8b. After several minutes the metal shelf holding the cardboard boxes collapsed onto the hoverboard and trash can. The security footage is soon obscured by smoke and soot on the lens but burning of the EV and ESS can be seen in Figure 8c. From audio, temperature, and gas data, we can distinguish several other

(a) Drill battery sparking during thermal runaway.

(b) Drill battery vent gas ignition during thermal runaway.

(c) Drill battery and waste bin contents burning.

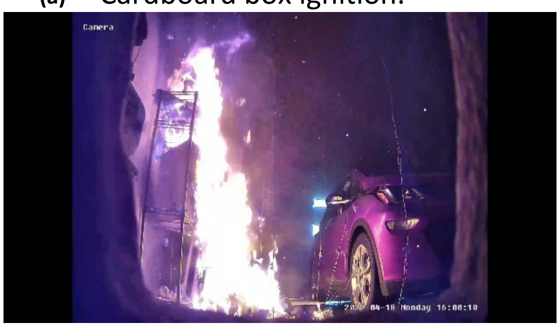
Figure 7. Drill battery fire progression.

subsequent ignitions throughout the test, which are outlined in table 1. Arcing from the failure of the ESS could be visually observed from outside of the garage as seen in Figure 9, as well as seen in the noisy voltage readings from numerous sensors. The garage door collapsed several minutes after the suspected failure of the ESS. After approximately 1 hour, fire services intervened and extinguished the fire. All batteries present went into thermal runaway except for the electric vehicle battery. All materials in the garage were consumed by the fire, including the EV frame and body as seen in Figure 10.

Temperature Data

The cell heater can be seen in Figure 11b. The cell temperature begins to rapidly increase after being heated to approximately 200°*C*. The cell temperature reached a peak of approximately 1100°*C* before beginning to cool. After the cell goes into thermal runaway, we can see from the security footage that the vent gas ignites and burns the paper and cardboard nearby. This ignition correlates with the increase in temperatures read on all other thermocouples. Several temperature peaks are seen in the grid thermocouples in Figure 11a at *T* = 1007*s*, *T* = 1119*s*, and *T* = 1366*s*. When compared with security footage, these peaks correlate with the successive ignition of cardboard boxes. Up until this point, we see a general trend of temperatures increasing as thermocouple height decreases. Temperatures globally increased until *T* = 2480*s*, where they reach a maximum of roughly 1100°*C* before decreasing due to fire service intervention. From *T* = 2000*s* onward significant noise is present, likely due to the arcing from

(a) Cardboard box ignition.



(b) Cardboard box burning and depositing flaming material onto batteries below.

(c) Late phase burning, possibly including ESS and EV.

Figure 8. Fire progression between flammable materials.

Event	Time Since Heater Start [s]
Cell Venting	866

Ignition	867
First Peak	1007
Second Peak	1091
Third Peak	1098
Fourth Peak	1118
Cell 3 TR	1329
Cell 2 TR	1360
Fifth Peak	1670

Table 1. Timeline of events, measured in seconds after the initiation of cell heating.

Figure 9. The energy storage system can be seen arcing from outside the garage, indicated by the white flash in the bottom right corner of the garage door.

the BESS, as described in section 3.1. As a result, the reliability of these measurements is compromised for the remainder of the test and any interpretations should account for this.

Heat Flux Data

Incident heat fluxes were measured using direction flame thermometers (DFTs). The literature value for

′′ [2] according to Khan et al. (2011). As the critical heat flux for ignition of cardboard, q_{cr}, is 8.0-9.0 *kW/m*

seen in Figure 12a, this value is surpassed at several times and locations throughout the test, which is consistent with the results of the test, in which all standard combustible materials were consumed. Figure 12b shows the heat fluxes incident on the battery energy storage system. The data ends at T = 1920s, as temperatures became excessively noisy due to ESS arcing.

Unlike for standard combustibles, there is not a known critical heat flux or critical flux-time product for characterizing lithium-ion battery failure and ignition. A maximum heat flux of 16.7 kW/m^2 was measured on the battery energy storage system. Another way to model ignition is through the flux-time product, or the integral over time of some incident heat flux greater than the critical heat flux required for ignition.

$$FTP = \int (q'' - q''_{cr})\,dt, \text{ where } (q'' - q''_{cr}) \geq 0 \quad (1)$$

The critical heat flux is equal to the heat lost through convection, such that the heat flux in excess of q''_{cr} is conducted into the system.

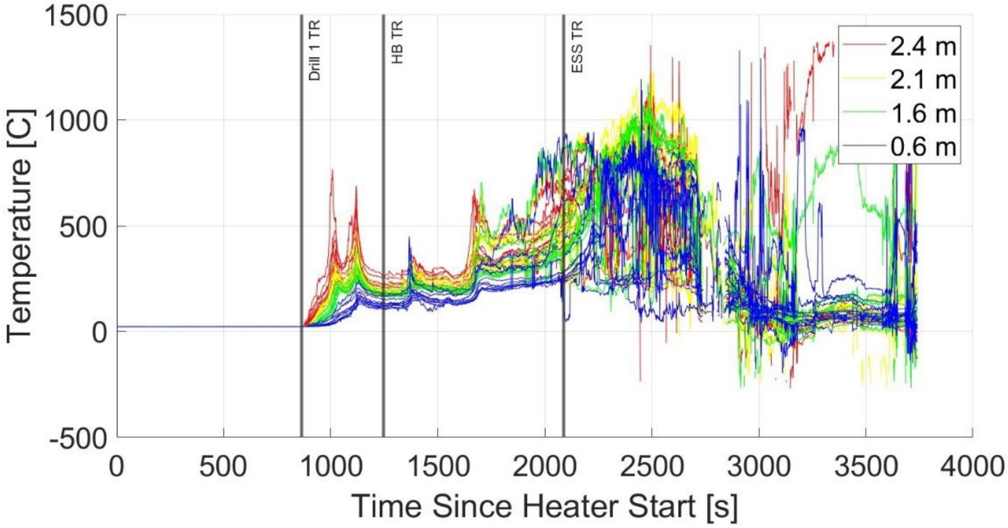
$$h(T_s - T_\infty) = q''_{cr} \quad (2)$$

Figure 13a shows the flux-time product calculated when $q''_{cr} = q''_{ambient}$. This FTP is shown to reach 4600-5800 kJ/m^2 during this period, though the value likely continued to increase for another 500-1000 seconds while the global temperature was above ambient. Another estimation of q''_{cr} was made by estimating a value for the critical heat transfer coefficient, h_{cr}, to be 39 W/m^2K Xu et al. (2022).

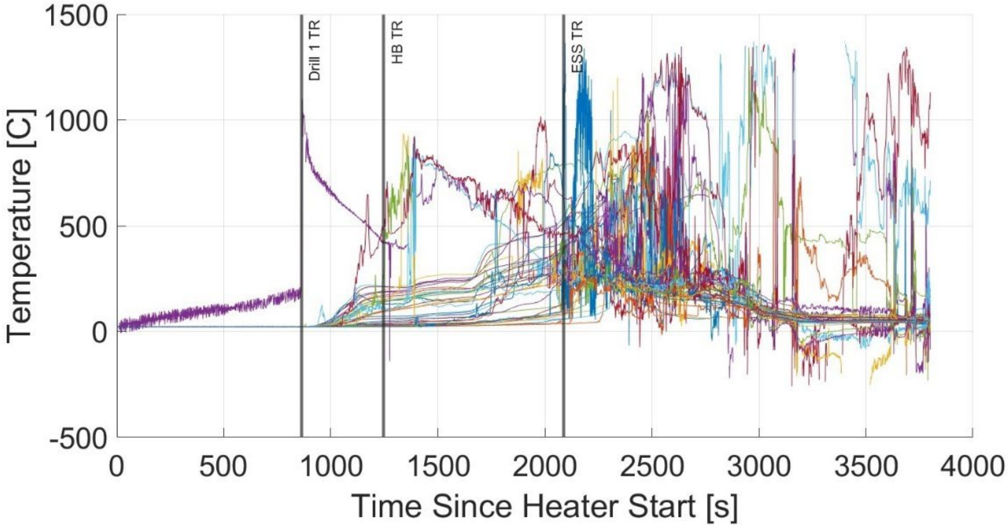
(a) Electrical vehicle post-test.

(b) Battery energy storage system post-test. **(c)** Garage after BESS and EV were removed.

Figure 10. Resulting damage from test.



(a) Temperature readings from grid thermocouples.



(b) Temperature readings from DFT and miscellaneous thermocouples.

Figure 11. Temperature readings from all thermocouples. The time since heater start is on the x-axis, measured in seconds.

$$h(T_s - T_\infty) = 39\ W/m^2K \times (180^\circ C - 25^\circ C) = 6.0\ kW/m^2 = q''_{cr} \quad (3)$$

This FTP is shown in Figure 13b to reach maximal values of 1700-2900 kJ/m^2, which, again, likely continued to increase beyond this period. Additional research is needed to determine critical heat flux, heat transfer coefficient, and flux-time product values.

The figures and values shown here were processed using a simple rolling average with a 10 second window on the raw calculated heat flux values in order to decrease noise present from electrical interference and resulting from insufficient temperature resolution at lower values. At low (ambient) temperatures, such as before the ignition of any materials, small differences of $0.1^\circ C$ between the front and back plate of the DFT produced noisy heat flux values between +20 and -20 kW/m^2, which is likely less representative of the heat fluxes present compared to the nearly constant 2.6-2.8 kW/m^2 calculated after using a rolling average window of 5-25 seconds. A 10 second window was chosen to best minimize noise while retaining peaks.

Gas Concentration Data

Gas concentration measurements were collected a various locations and heights inside the garage. In-house gas analyzer boxes, shown in figure 14, measured oxygen, carbon dioxide, and methane concentration. The gas boxes used a Non-Dispersive Infrared (NDIR) sensor (Sensortech model number IR15TT-R), and an electrochemical oxygen sensor (Maxtec model number Max-13). Kennedy (2021) described the methane sensor to perform "poorly for battery vent gas" due to the sensor being "far more sensitive to other hydrocarbons than to methane". Several firefighter multi-gas sensors were deployed. An Alair 4XR was placed in the garage, and measured LEL, oxygen, carbon monoxide, and hydrogen sulfide concentrations. Several MultiRAEs were deployed across the street from the structure, but none detected any significant quantity of gas due to distance from the garage. Figures 15a and 15b show the concentrations from the gas boxes and Figure 16 shows readings from the Altair.

From the trends found in our previous work, we can estimate the probable volume and composition of all gases released from lithium-ion batteries thermal runaway during the test. Volume of gas production is shown scale with battery capacity Baird et al. (2020) and state of charge (SOC). A 100% SOC LFP battery will, on average, produce 0.27 L/Wh, while a 100% SOC NMC cell will produce 0.49 L/Wh.

$$For\ BESS: 10.24\ kWh \times 0.27\ L/Wh = 2800\ L\ vent\ gas \quad (4)$$

$$For\ Hoverboard: 160\ Wh \times 0.49\ L/Wh = 78\ L\ vent\ gas \quad (5)$$

$$For\ Drills: 3 \times 20\ Wh \times 0.49\ L/Wh = 29\ L\ vent\ gas \quad (6)$$

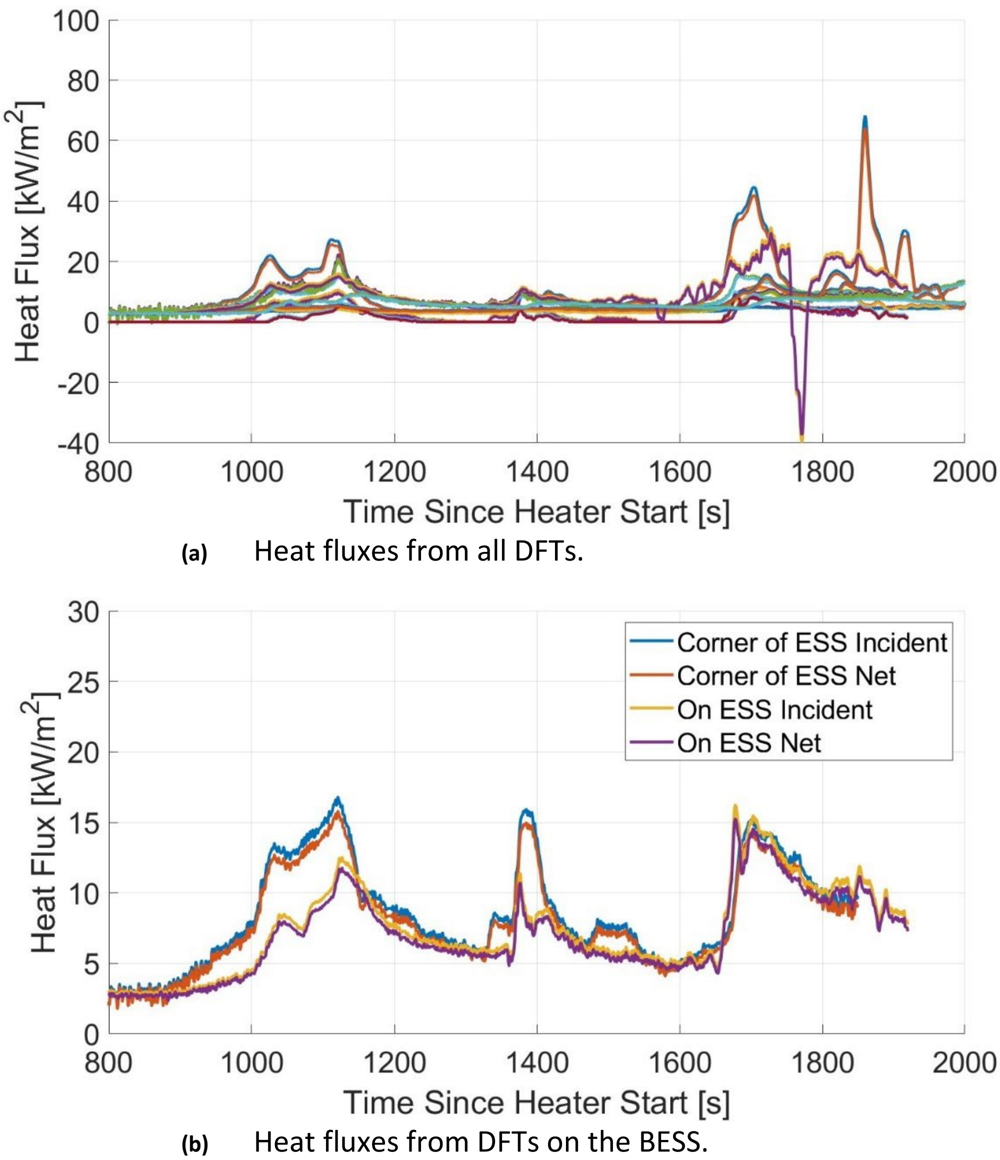
Approximately 2900 L, or 2.9m^3 of vent gas would have been released from the various batteries during the test. We can estimate the volume of the garage to be 90m^3.

$$6m \times 6m \times 2.5m = 90m^3 \quad (7)$$

This equals a concentration of vent gas of 3.2%, which is below the known LEL of battery vent gas of approximately 6% LEL.

$$2.9m^3/90m^3 = 3.2\% \quad (8)$$

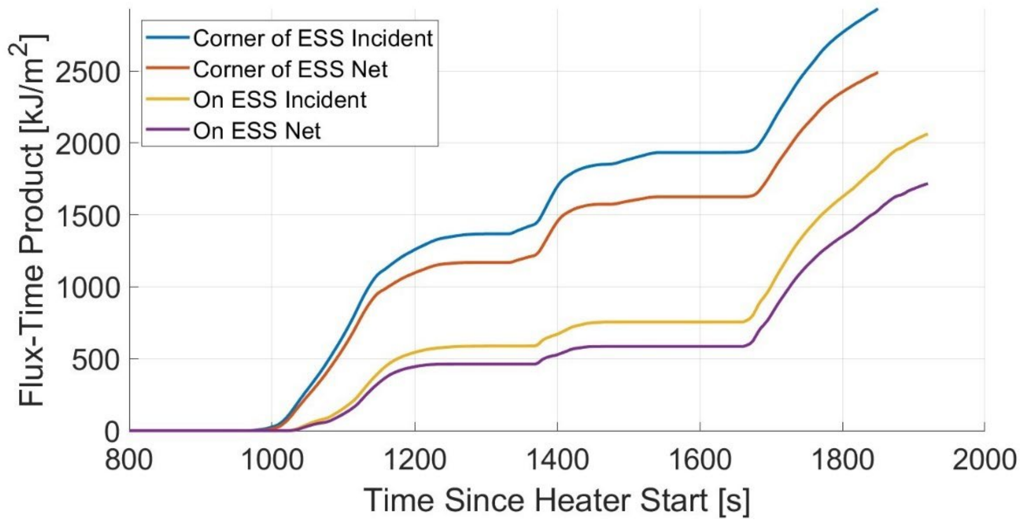
Assuming a fully mixed environment, this would not be consistent with the known ignition that occurred during the test. However, if we assume a partially premixed or partial volume deflagration, this volume of battery vent gas is within the flammable range (Archibald et al. (2021). There is a high correlation between the increased concentration of carbon dioxide and the decreased concentration of oxygen. Starting at around *T* = 2000*s*, the concentration of oxygen decreases, and the concentration of carbon dioxide increases sharply. This is likely due to the large volume of gas released during thermal runaway of the BESS, as shown in equation4. Oxygen concentrations were measured to drop to 0%-5% during the test, while carbon dioxide concentrations peaked at 15%-20%. After *T* = 2500*s*, the carbon dioxide concentration decreases and the oxygen concentration increases, which correlates with the garage door



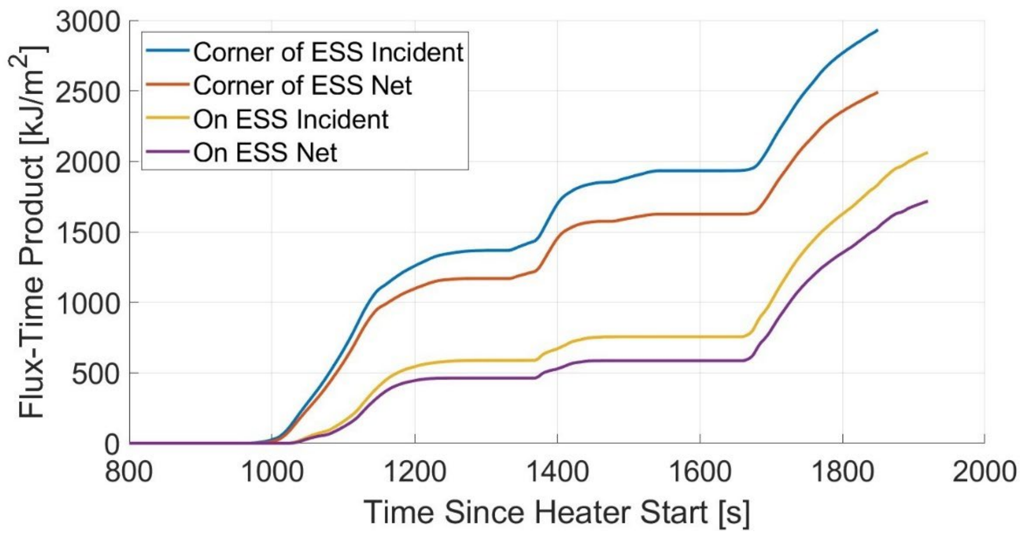
(a) Heat fluxes from all DFTs.

(b) Heat fluxes from DFTs on the BESS.

Figure 12. Heat flux values.



(a) Flux-time product of DFTs on the BESS. Ambient heat fluxes were subtracted before calculating.



(b) Flux-time product of DFTs on the BESS. An assumed q_{crit} of 6.2 kW was subtracted before calculating.

Figure 13. Approximate flux-time products incident on the BESS throughout the test.

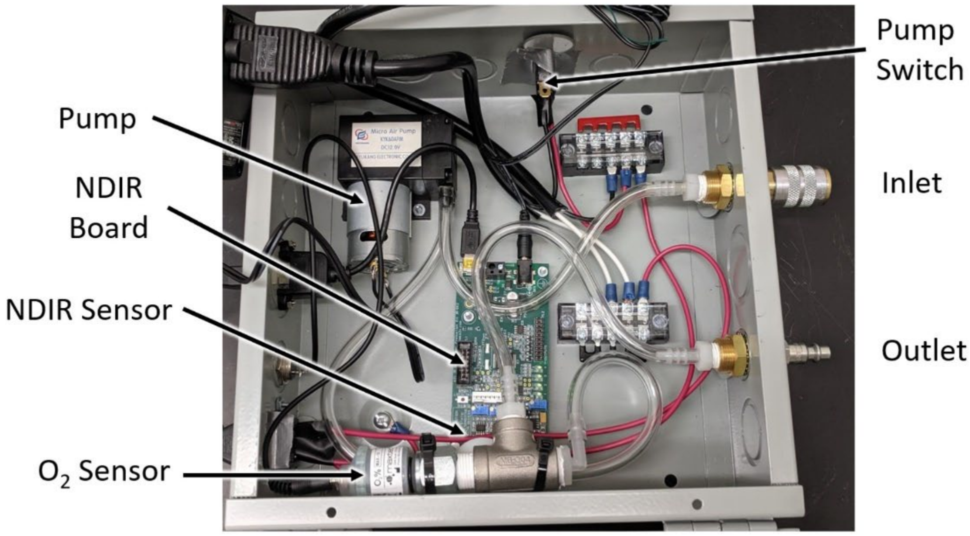


Figure 14. In house-built gas box. Figure used with permission from Kennedy (2021).

collapsing, likely increasing the flow of fresh air into the garage. Two sampling points, close middle and far top, did not record significant data throughout the test. There was not a clear trend between heights, sampling locations, and gas concentration.

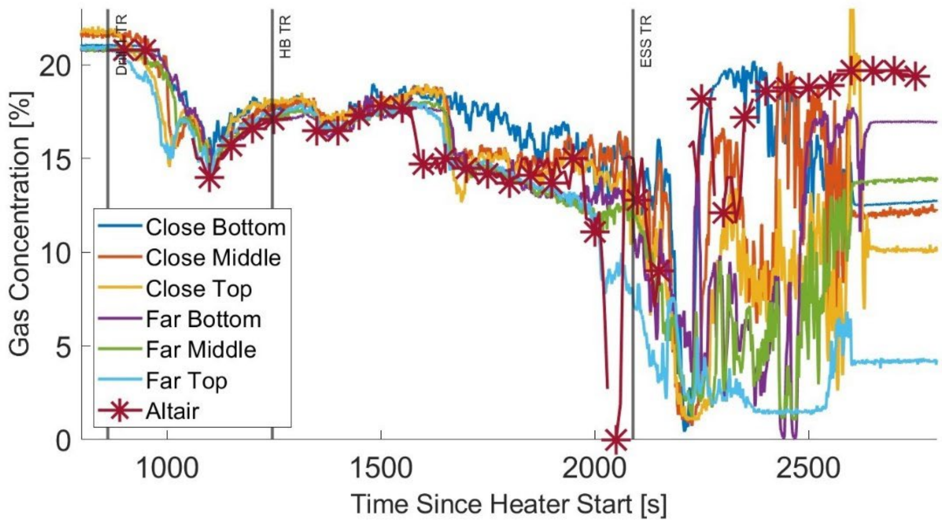
The oxygen concentrations measured by the firefighter multi-gas sensor correlated well with those measured by the gas boxes 15a. LEL readings peaked at 28% during the test. Care should be taken when interpreting values measured by catalytic LEL sensors. Sensors are frequently calibrated to methane gas; however, hydrogen gas and other hydrocarbons are known to be produced during battery thermal runaway. Each gas elicits a different response in the sensor, and thus any non-methane gaseous environments will be measured incorrectly without the appropriate conversion factor. The multi-gas sensor also measures carbon monoxide and hydrogen sulfide, with IDHL values of 1200ppm and 100ppm, respectively. The carbon monoxide sensor maximally reads 3000ppm and was saturated for a large duration of the test. The hydrogen sulfide concentrations peaked at 99ppm, however some fraction of this concentration could be due to the sensors' cross sensitivity with carbon monoxide (shown in table). A minimum of 30 ppm would have been due to carbon monoxide (3000 ppm $CO \times 0.01 = 30$ ppm), however, due to the true maximal carbon monoxide concentration being unknown, we cannot know definitively what portion of the hydrogen sulfide reading was due to cross sensitivities.

CONCLUSIONS AND TAKEAWAYS FOR FIREFIGHTERS

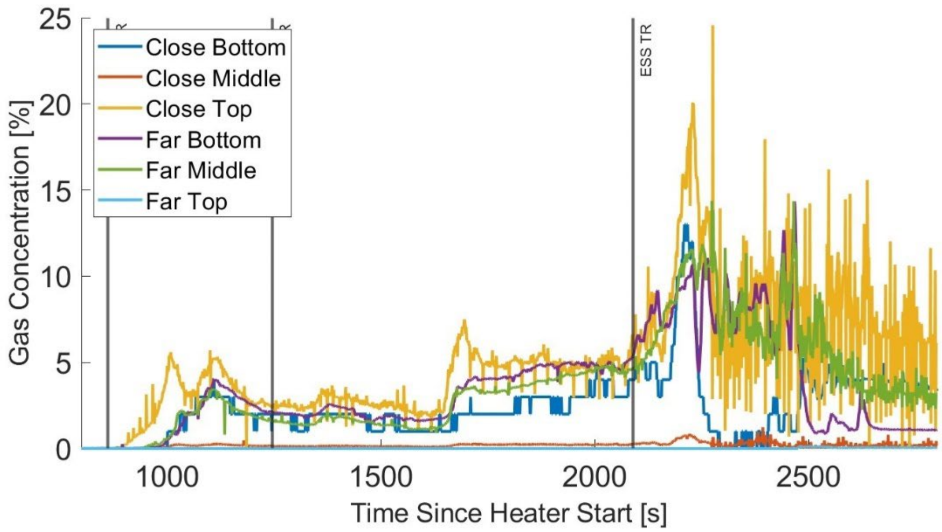
Lithium-ion batteries were burned in a residential garage to study the fire spread process in fires involving battery systems. Temperature, heat flux, and gas concentrations were made. All batteries except the electrical vehicle battery went into thermal runaway. Several variables could account for this, including the low state of charge of the battery, or the design and insulation of the EV battery modules.

There are several takeaways for firefighters that we can conclude from this test. Firefighters should take care when interpreting readings from multi-gas sensors, as reading are not necessarily representative of the actual gaseous environment due to cross sensitivities of different gases on a given sensor. Knowledge of the expected environment can allow firefighters to apply appropriate correction factors to better interpret the readings. During the test there was significant arcing from the battery energy storage system while it failed. Firefighters should recognize that there are arcing hazards associated with batteries that have been exposed to fire. Appropriate precautions should be put in place for the resulting electrical hazards.

Proper extinguishment, management and disposal of lithium-ion batteries that have been exposed to high temperatures is critical to prevent additional ones from occurring. As we learned from this test, a cell may not enter thermal runaway while exposed to high temperatures, especially if the battery was at a low state



(a) Oxygen concentrations measured by gas boxes and HAZMAT sensor.



(b) Carbon dioxide concentrations measured by gas boxes.

Figure 15. Gas concentrations measured at various locations in the garage.

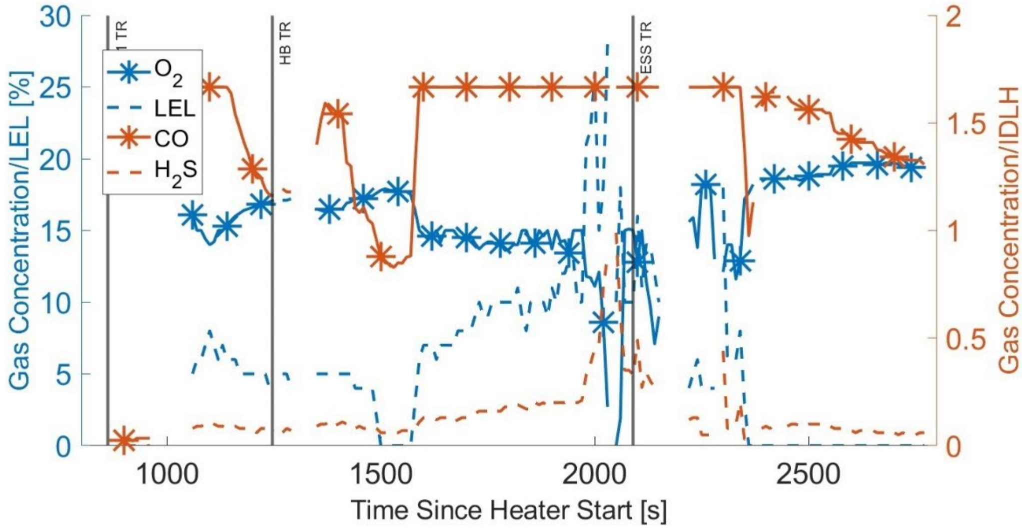


Figure 16. LEL, *O_2*, *CO*, and *H_2S* concentrations measured by the Altair.

of charge. During our test, the body of the electric vehicle was consumed completely, and yet the cells did not go into thermal runaway. However, an intact battery may still be damaged, and could enter thermal runaway hours or days later as the battery damage continues to progress. This should inform several protocols when addressing a battery fire. First, the EV or BESS should be removed from the residence to prevent additional structural damage in the case of re-ignition. Second, precautions should be taken by personnel when transporting a potentially damaged battery, again in case of a delayed failure. Third, batteries are only safe for disposal if they are discharged to 0% SOC or are known to have gone into thermal runaway. Additional research is needed to explore the safest and more optimal method for first responders to identify, discharge, and dispose of intact yet damaged batteries.

ACKNOWLEDGMENTS

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Appendix B: **NFPA FIRST Frequently Asked Questions (FAQ) Guide**

NFPA FIRST (Firefighters Incident Response Simulation Tool) APP
Frequently Asked Questions

General Information

Q: What is the purpose of the NFPA FIRST training application?
A: This application is designed to provide firefighters with a realistic and immersive simulation to train in responding to and extinguishing fires with Distributed Energy Resources present. The first scenario in the application is about fighting an electric vehicle fire inside a single-family home's garage.

Q: What game engine does the application use?
A: The training application is built using Unreal Engine 5.3 for the Windows platform. With the Unreal Engine, trainees no longer must compromise. They will get accurate and authentic training in the most realistic way possible. You can read more about Unreal Engine 5 here: https://www.unrealengine.com/en-US

Q: I have a problem with the FIRST application. Who do I contact?
A: Please contact our support team at MRDENorthAmericaTeam@GHD.com

Q: I want to make a suggestion. Who do I contact?
A: You should contact the NFPA at https://www.nfpa.org/

Q: Will there be more scenarios or levels to complete? Who do I contact to suggest more content for FIRST?
A: You should contact the NFPA at https://www.nfpa.org/

Q: What are the minimum supported computer requirements?
A: The minimum specifications are:

Processor (CPU):
AMD Ryzen 5 2600 or
Intel Core i5-7400 (or equivalent)
Graphics Card (GPU):
NVIDIA GTX 1050 Ti – 4GB or
AMD Radeon RX 560 (or equivalent)
RAM:
8GB DDR4
Storage:
6GB (SSD - Solid State Drive for faster loading times)
Operating System:
Microsoft Windows 10 64-bit

Q: How well is FIRST optimized?
A: We put forth our best efforts to ensure the game runs at its best within the confines of the user's CPU and GPU capabilities. If you do not meet the above supported minimum requirements, you may not have the best experience.

Q: My internet connection is very slow. Is there a physical copy of the application available?
A: Unfortunately, no physical copies of the game are available.

Q: Is the application multiplayer?
A: Yes, you can play FIRST with up to five people on a local area network.

Q: How do I communicate with other players in the game? Is there voice-over-IP or a radio?
A: Yes, you can communicate with other players in multiplayer sessions. There is a built in-game VOIP/radio. You can communicate with other players by pressing R on the keyboard or right shoulder on the gamepad.

Q: What language is FIRST in?
A: The FIRST application is in English only currently.

Q: What accessibility options does FIRST have? Does FIRST meet ADA requirements?
A: FIRST meets the suggested requirements for accessibility as required by the ADA. This includes accessibility for colorblindness, a low contrasting color scheme, keyboard-only (or gamepad) navigation through the user interface, captions for all media, and more. You can read more about ADA requirements here: https://www.ada.gov/

Q: Can I play FIRST in virtual reality?
A: Currently, the FIRST application is not designed for VR.

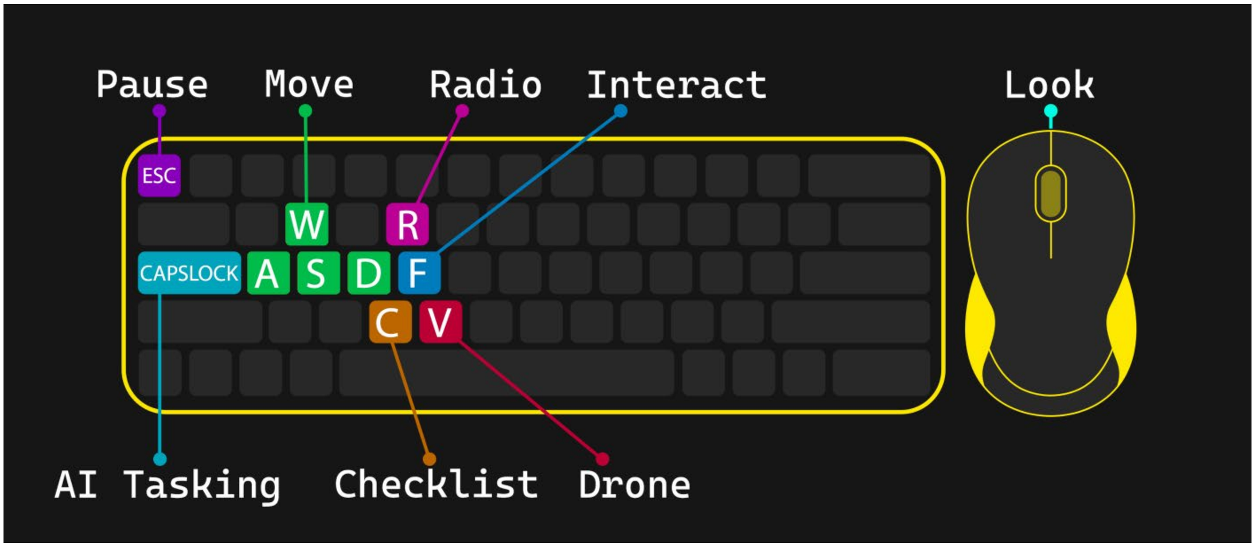
Q: Can I adjust other settings besides what is listed in the options screen?
A: Currently there are no plans to add additional settings to the application.

Q: Are there leaderboards?
A: Yes, your timed score, if you complete the scenario correctly, is logged on the computer for all to see. You can continue to replay the scenario to get a better time.

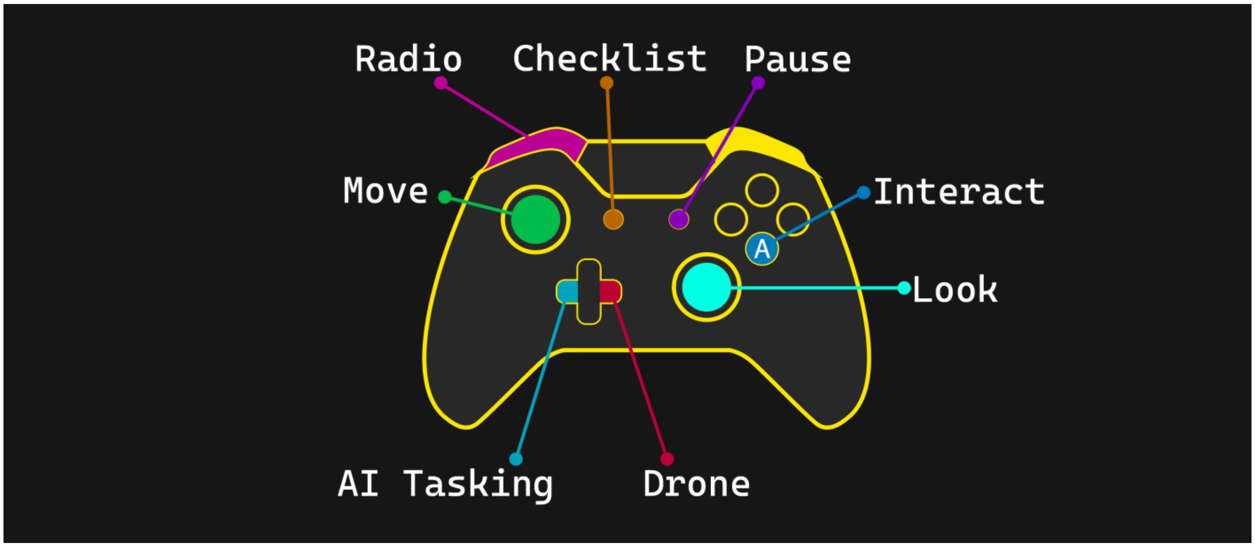
Q: How do I end the scenario?
A: Conclude the scenario at your convenience by approaching the Commander's vehicle and initiating the End Scenario interaction. Upon ending the scenario, your performance will be scored, reflecting your accomplishments and decisions throughout the virtual experience.

Controls

Q: Can I get a visual representation of the application's controls?
A: Yes, see below.



Q: Can I use a gamepad or controller with FIRST?
A: Yes, any Windows compatible game controller device should work with the FIRST application. We recommend the Xbox game controller.



Q: How do I navigate the user interface with keyboard accessibility?
A: Use the arrow keys to navigate the user interface, press spacebar to 'click' a button, and press tab to move to the next set of buttons.

Q: What are the basic movement controls?
A: Use either the WASD keys or arrow keys on the keyboard or use the gamepad's left thumbstick for moving forward, backward, left, or right. Use the mouse or the gamepad's right thumbstick to look around and control the direction you move.

Q: How do I activate the drone mode?
A: You must be the Commander (first player) to use the drone view. Press the V key on the keyboard or right D-Pad to enter drone mode, allowing you to explore the environment from different perspectives. Once in drone mode, use the WASD keys or the arrow keys on the keyboard or the left thumbstick on the gamepad to control the drone's flight direction. Use the mouse or the right thumbstick on the gamepad to control view direction. Pressing V or right D-Pad again will exit the drone mode.

Q: How can I take control of the AI officers?
A: You must be the Commander (first player) to command the AI officers. Assign tasks to your AI officers by activating the context-sensitive menu with the Caps Lock key on the keyboard or the left D-Pad button on the gamepad. Choose the specific officer you want to assign a task to, and then select the desired action from the menu. Your AI officer will promptly carry out the task if available.

Q: How do I interact with objects in the world?
A: To engage with the game environment, approach interactive objects and initiate interactions by pressing the F key on your keyboard or the A button on your gamepad.

Q: How do I talk to other players in the module?
A: In multiplayer games, you can talk to other players via the in-game radio/VOIP. Press and hold R on the keyboard or left shoulder button on the gamepad to use the in-game radio. Just like a real radio, you will hear a beep. After the beep, speak into your microphone and other players will hear you talk in the game. Release R on the keyboard or left shoulder button on the gamepad to end talking on the radio. You will hear another beep confirming your radio is off.

Q: Can I pause the game at any time?
A: If you are the first player in a multi-user session, or you are playing the training solo you can press either escape on the keyboard or the start button on the gamepad to pause the game.

Q: How do I open the checklist?
A: In solo sessions or as the commander in multi-user sessions, you can view the checklist by pressing C on the keyboard or select on the gamepad. This feature allows you to view all the tasks essential for successfully completing the scenario. You can dive further into the checklist by selecting a specific checklist row to gain detailed insights into that task, ensuring a comprehensive understanding of your objectives.

Troubleshooting

Q: The application is giving an error when installing. It wants me to add DirectX to my computer. Is this safe to add to my computer?
A: These files are provided by Microsoft and should be safe to use. Direct X is already part of Windows 10 and Windows 11. If you do not have this installed already your administration team may have uninstalled on your computer. We recommend contacting them to get it installed. Direct X is required to run any Unreal Engine application. You can get the latest version of Direct X here:
https://www.microsoft.com/en-us/download/details.aspx?id=35

Q: While installing, the application wants to add Visual C++ Visual Runtime to my computer. Is this safe for my computer?
A: These files are provided by Microsoft and should be safe to use. C++ Visual Runtime is required to run any Unreal Engine application. You can get the latest version of the C++ Visual Runtime here:
https://www.microsoft.com/en-us/Download/confirmation.aspx?id=48145

Q: The application will not open at all and I get an error. How do I resolve this?
A: Ensure that your system meets the minimum requirements for the application. Try reinstalling the application, and if that fails contact support at MRDENorthAmericaTeam@GHD.com

Q: I'm experiencing performance issues like slow and jumpy response and graphics. What should I do?
A: Ensure that your system meets the minimum requirements for the application. The application is set up to start with the minimum specifications already – unless you have saved the graphic settings to a higher option. Check the options menu in the game to ensure that you have the lowest graphic settings.

Q: The controls are not responsive. How can I fix this?
A: Check your input devices to ensure they are properly connected. It is recommended to use a mouse and not a trackpad of a laptop to play FIRST. If the issue persists, try restarting the application.

Q: I'm stuck at a particular stage of the simulation. Any suggestions?
A: Review the training materials provided and ensure you are following the correct procedures. If you're still having difficulties, restart the simulation and try again.

Q: How do I force the simulation to end if I'm having trouble?
A: You can press and hold ALT+F4 to end the sim.

Q: The screen is stretched off my monitor. How can I fix this?
A: Press ALT+ENTER on the keyboard to switch between full screen and windowed mode.

Q: I cannot join or see my friend's multiplayer session. What should I try?
A: Sessions only work on local area networks. Check your network settings to ensure you and your friend are on the same network. If the problem persists, check your firewall settings.