Hazard Dynamics

Hillman Energy Center Emissions of Carbon Monoxide and Volatile Organic Compounds from BESS Fires

HD-25030-Hillman Energy Center-CO-1.0

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Prepared for:

Hillman Energy Center, LLC

By:

Anne Marie Hawkins
Anna Jensen
Kevin Marr, Ph.D. P.E.
Erik Archibald, Ph.D. P.E.

Hazard Dynamics LLC
PO Box 1967
Pflugerville, TX 78691 USA

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1 Executive Summary

A study was conducted for the Hillman Energy Center BESS (battery energy storage system) site to determine toxicity hazards that may be posed to nearby areas during possible battery failure scenarios. The study considers carbon monoxide (CO) and volatile organic compounds (VOCs) that can be released by Li-ion batteries during thermal runaway failures. Computational fluid dynamics (CFD) models were utilized to simulate plumes resulting from theoretical battery failure scenarios. The following scenarios are considered (1) a non-fire scenario in which battery vent gas is released, (2) a small fire scenario, and (3) a large fire scenario. The fire scenarios considered low and high wind conditions based on nearby meteorological data.

Based on the modeled scenarios, CO and VOC concentrations 2 m (6.6 ft) from ground level were estimated using Fire Dynamics Simulator (FDS), which is a CFD software developed by the National Institute of Standards and Technology (NIST) for fire modeling. A summary of the findings of the study is as follows:

- The fire scenarios with high wind conditions resulted in the highest modeled CO and VOC concentrations at 2 m (6.6 ft) from ground level. The modeled average carbon monoxide concentrations may cause serious health effects (exceed the AEGL-2 level) up to approximately 118 ft (36 m) from the burning enclosure in a large fire scenario with high winds. The modeled high wind speed was 22 mph (10 m/s), which is the 99th percentile wind speed for the Hillman Energy Center site. For first responders who may be operating within this region, guidance for appropriate personal protective equipment (PPE) can be found in relevant Emergency Response Protocol (ERP) documents.
- A house is approximately 80 ft away from the Hillman Energy Center site, several commercial buildings are as close as 157 ft, and a church approximately 0.7 mi away. Based on the model results and the prevailing wind direction at the site, it is possible that carbon monoxide could cause serious health effects (reach AEGL-2 levels) at the nearest house, but it is unlikely that other nearby buildings will experience toxic levels of carbon monoxide in the event of a single BESS unit experiencing a failure event.
- Volatile organic compounds (VOCs) make up only trace amounts of the battery vent gas. VOC release quantities are too small to exceed hazardous levels at any distance from the unit.

Note that this Executive Summary does not contain all of Hazard Dynamics' technical evaluations, analyses, conclusions, and recommendations. Hence, the main body of this report is at all times the controlling document.

2 Introduction

This report describes the results of a carbon monoxide (CO) and volatile organic compound (VOC) dispersion study conducted for the Hillman Energy Center battery energy storage system (BESS), which is being constructed for East Point Energy in Tewksbury, MA. The Hillman Energy Center site uses the Hithium Block for lithium-ion battery energy storage. The purpose of this toxicity study is to identify and quantify potential risks associated CO and VOCs produced by a BESS under abnormal conditions.

Where appropriate data is unavailable, reasonable engineering assumptions will be made. These assumptions will be drawn from the available body of technical literature. This analysis was conducted using a set of probable worst-case scenarios based upon available test data such as UL 9540A reports and includes up to a fully-involved fire in a single unit.

This report will first provide background on the carbon monoxide and volatile organic compound toxicity hazards of lithium-ion battery systems. Next, it will review the details of the

Hillman Energy Center site as well as the energy storage system itself. Finally, the report will evaluate possible toxic carbon monoxide and volatile organic compound scenarios and their consequences.

This analysis relies on the following information:

- Plans for the Hillman Energy Center site [1] [2] [3]
- UL 9540A Cell test report for cell model LFP71173207/314Ah, UL (Changzhou) Quality Technical Service Co., LTD report number 4791072813 dated 2/27/2024 [4]
- UL 9540A Module test report for module model LM010401-A, TUV Rheinland (Shenzhen) Co., Ltd. report number CN23XXY9 003 dated 5/11/2024 [5]
- UL 9540A Unit test report for unit model LC083502, TUV Rheinland (Shenzhen) Co., Ltd. report number CN244DBX 001 dated 4/26/2024 [6]
- Hithium manual and datasheet for the Hithium Block system [7][8]

3 CO and VOC Toxicity Hazards

Abuse and failure of lithium-ion cells may result in gas production inside of the cells. When enough gas is produced, a safety vent may open, or the cell package may rupture. The gas mixture released is flammable and toxic and is primarily made up of carbon monoxide (CO), carbon dioxide (CO_2), hydrogen (H_2), and an assortment of hydrocarbons. If ignited, the combustion of these gases can lead to a fire or an explosion.

Smoke from many fires, including battery fires, is considered hazardous. Toxicity hazards during failure of lithium-ion batteries may exist alone or in combination with fire and explosion hazards. A significant amount of the gas released during thermal runaway is carbon monoxide (CO), which is toxic. Depending on the conditions, the combustion of battery gases may burn off some carbon monoxide or create additional carbon monoxide from partially reacted hydrocarbons. Smaller amounts of other toxic gases, such as volatile organic compounds (VOCs), may also be released.

3.1 Toxicity Reference Levels

In evaluating harmful levels of toxic gases, it is helpful to reference levels known as IDLH (immediately dangerous to life or health) and AEGLs (acute exposure guideline levels). According to the Code of Federal Regulations, IDLH is defined as a concentration of any toxic, corrosive, or asphyxiant substance that poses an immediate threat to life, would cause irreversible or delayed adverse health effects, or would interfere with an individual's ability to escape from a dangerous atmosphere [9]. IDLH values were developed to address occupational exposures to chemicals and to help protect workers from acute or short-term exposures to high concentrations of some airborne chemicals that could result in undesirable health outcomes [10]. The AEGLs were developed by the EPA to define the health effects of a once-in-a-lifetime exposure to airborne chemicals. AEGLs are used by emergency responders when dealing with major chemical leaks, spills, or other exposures. AEGL concentrations are provided for different exposure times and health effect levels. Level 1 is discomfort or irritation, Level 2 is the onset of irreversible or serious health effects, and Level 3 describes life-threatening health effects [11]. Table 1 shows the IDLH, AEGL-2, and AEGL-1 concentrations for carbon monoxide, carbon dioxide, and some toxic volatile organic compounds that may be present in battery gas. The AEGL values presented in the table are based on an exposure time of 30 minutes, which is characteristic of how long someone evacuating might be exposed to a substance.

Table 1: Toxic concentration thresholds for carbon monoxide, carbon dioxide, and some toxic volatile organic compounds that may be present in battery gas. The AEGL values shown are for a 30-minute exposure. (NR = Not recommended due to insufficient data)

Chemical	IDLH (ppm)	AEGL-3 (ppm)	AEGL-2 (ppm)	AEGL-1 (ppm)
Carbon Monoxide (CO)	1,200	600	150	NR
Carbon Dioxide (CO_2)	40,000	NR	NR	NR
Benzene (C_6H_6)	500	5,600	1,100	73
Toluene ($C_6H_5CH_3$)	500	5,200	760	67

4 Site and System Descriptions

4.1 Site Description

The Hillman Energy Center project is a lithium-ion BESS facility that will be located in Tewksbury, MA and is approximately 20 miles northwest of Boston. The location of the site can be seen in Figure 1.

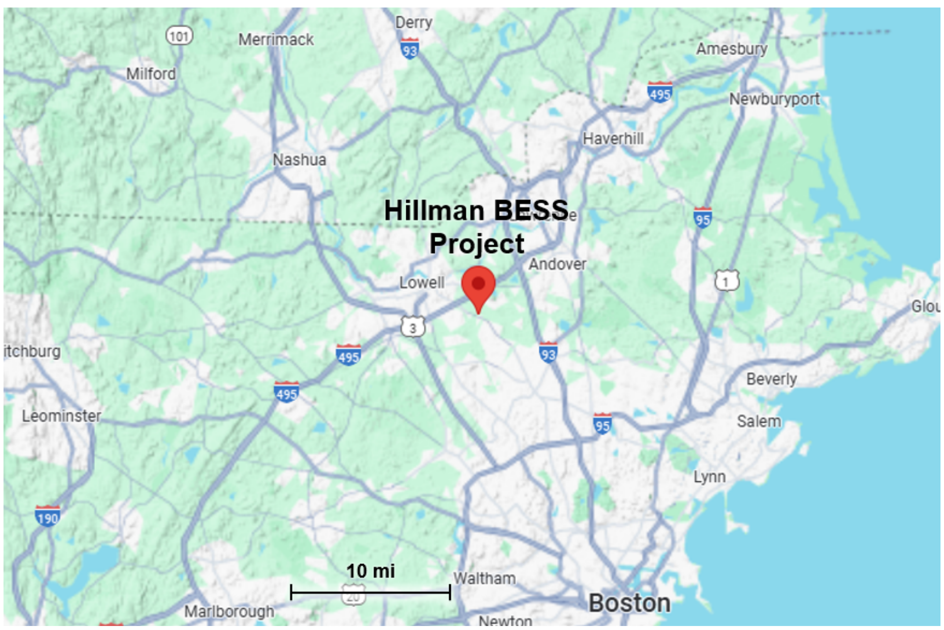
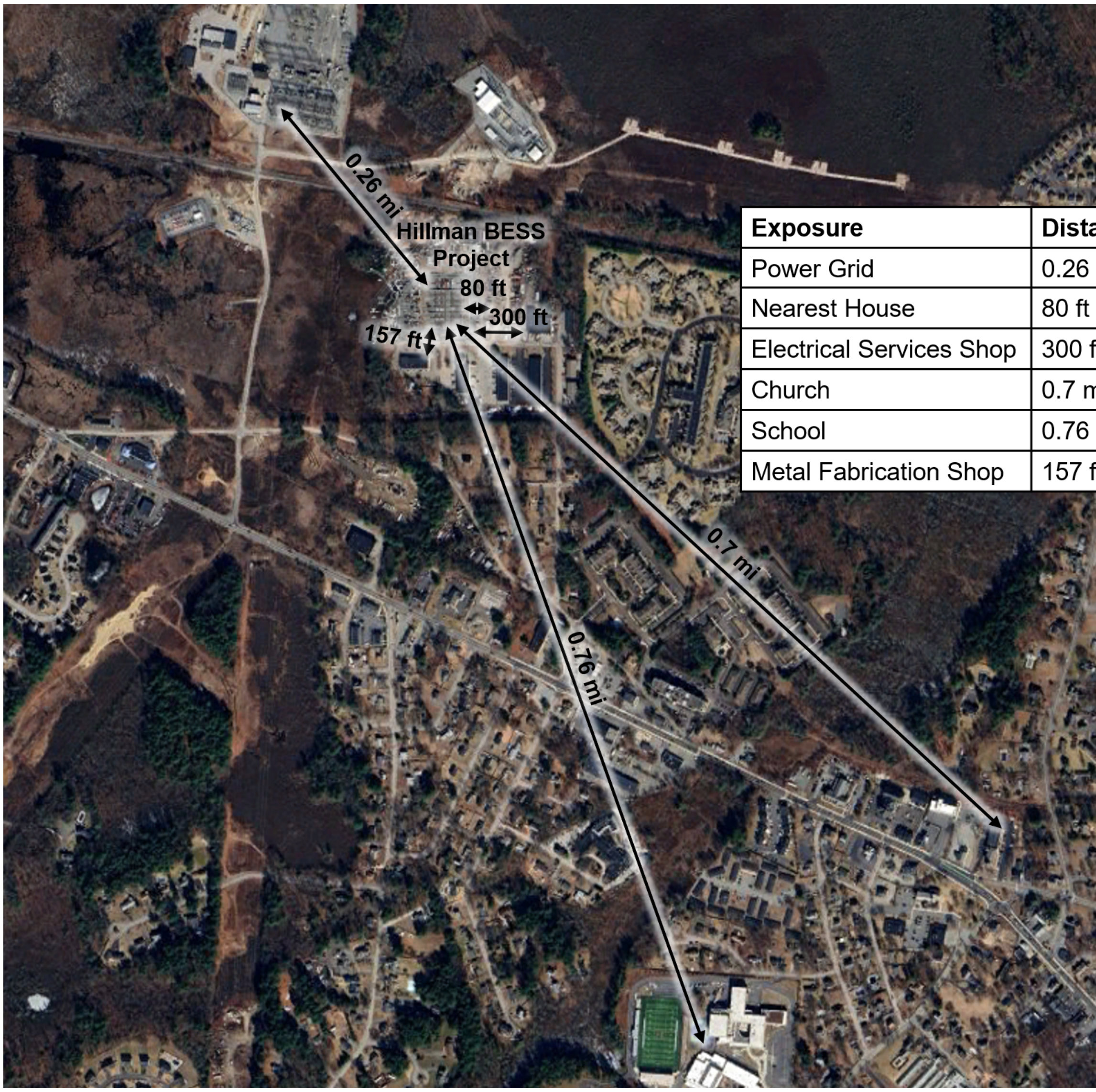


Figure 1: A map showing the location of the Hillman Energy Center site. This image was taken from Google Maps 2025.

The project will be located on 4.05 acres of land and includes lithium-ion battery energy storage equipment [1]. It is planned for development in a wooded area, with several local businesses located as close as 157 feet from the site. The nearest residence is approximately 80 feet away. Other nearby points of interest include a church located 0.7 miles from the site and a school 0.76 miles away. The site and its close surroundings are shown in Figure 2. Nearby exposures and their approximate distances from the BESS are also shown in Figure 2.



Exposure	Distance
Power Grid	0.26 mi
Nearest House	80 ft
Electrical Services Shop	300 ft
Church	0.7 mi
School	0.76 mi
Metal Fabrication Shop	157 ft

Figure 2: A satellite view of the Hillman Energy Center site location and its surroundings with the site drawing overlaid. Nearby exposures are shown with their distances from the nearest BESS enclosure. This image was produced using Google Earth Pro and Google Maps.

4.1.1 Typical Wind Conditions

In case of a toxic gas release, it is expected that the impacted area would be downwind of the site. The closest weather station for historical data is the Lawrence Municipal Airport site. According to historical wind information from 1979-2025, the prevailing winds generally come from the south-southwest, with a significant amount coming from the west (see Figure 3). The average wind speed is 8 mph or 3.6 m/s. Conditions are calm 12.4% of the time [12]. Because a large percentage of wind speeds exceed 20 mph on the wind rose, wind data was further analyzed to find the 99th percentile wind speed for use in the plume model. This wind speed was found to be 22 mph or 10 m/s.

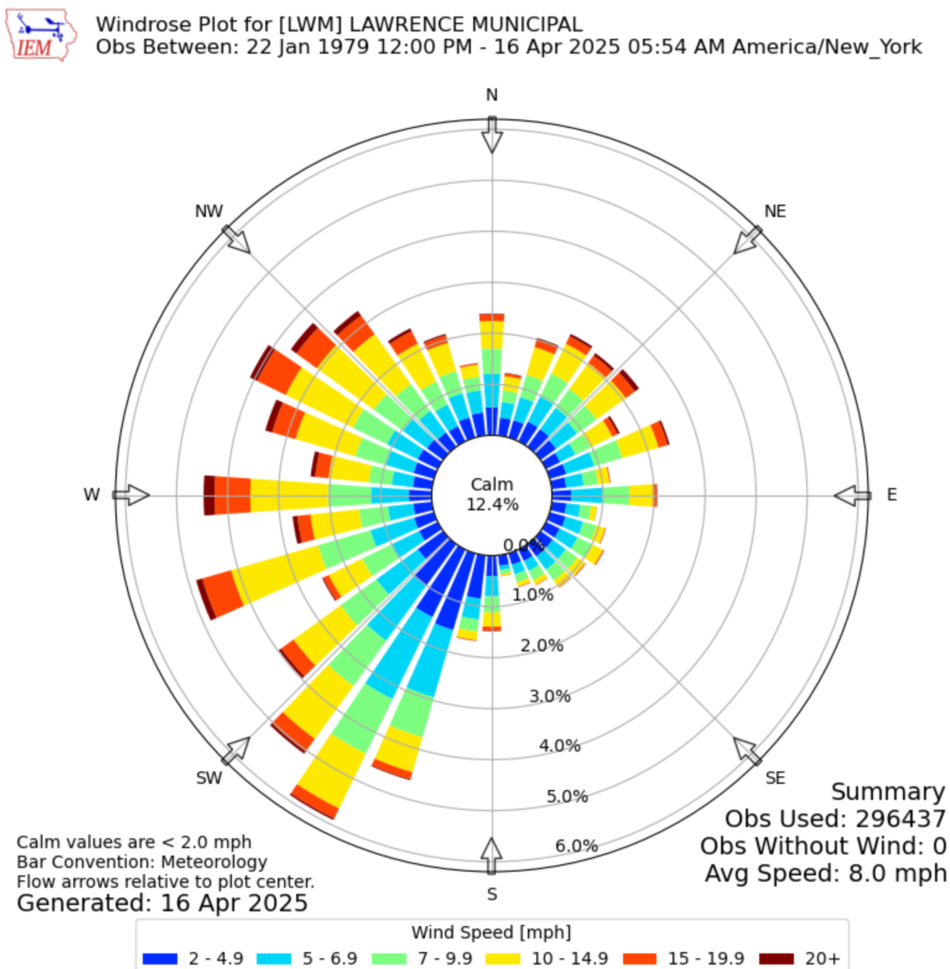


Figure 3: The wind rose for the Lawrence Municipal Airport weather station, which is the closest available station to the Hillman Energy Center site. This image was taken from the Iowa State University Environmental Mesonet website [12].

4.2 Energy Storage System Description

The Hillman Energy Center project will use Hithium Block battery units made by Hithium for energy storage. These units contain Xiamen Hithium Energy Storage Technology Co., Ltd lithium-ion batteries installed in racks inside the enclosure. Each enclosure contains six racks of eight modules each for a total of 48 liquid-cooled battery modules. The Hithium Block contains racks, a control panel, high-voltage (HV) boxes, a thermal management system, a fire protection system, and a ventilation system. The layout and features of the Hithium Block can be seen in Figure 4 [7].

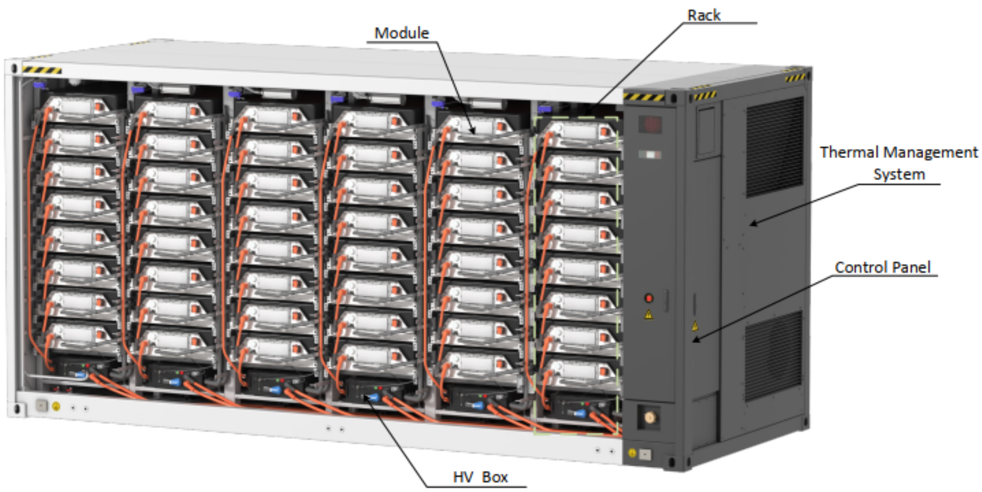


Figure 4: An image of a Hithium Block battery energy storage system. [7].

The Hillman Energy Center site will include a total of 134 Hithium Block enclosures. The site also includes power conversion systems and other equipment. Figure 5 shows the planned layout of the site.

Figure 5: An engineering drawing indicating the planned layout of the Hillman Energy Center site, including the battery enclosures, power conversion systems, and other equipment [2].

5 UL 9540A Test Results

This analysis is based on test data from UL 9540A cell, module, and unit test results. During this testing, a cell is forced into thermal runaway while the outcome is observed. Gases released from the battery or batteries during thermal runaway are captured and analyzed for select chemical species. Depending on the outcome of cell-level testing, additional testing at the module level and full unit level may also be required. For this plume analysis, UL 9540A data from cell-level [4], module-level [5], and unit-level [6] testing was reviewed. The results of these tests are described in Sections 5.1-5.3.

Since UL 9540A is primarily concerned with fire and explosion hazards, typical UL 9540A gas measurements are focused on major combustible gases and combustion products, such as hydrogen, carbon monoxide, carbon dioxide, and various hydrocarbons. Typically, carbon monoxide is the most significant toxicity hazard among the measured gases due to a comparatively low IDLH value and relative abundance in most battery gas. The UL 9540A test report for the Xiamen Hithium Energy Storage Technology Co., Ltd cells indicates that 171.2 L of gas was captured from a single cell. Of the gas captured, 14.507% by volume was carbon monoxide. This information, along with the remaining composition information, is listed in Table 3.

Cell-level gas composition information is collected by failing an individual cell inside of a sealed pressure vessel that is filled with an inert gas to prevent combustion. This method allows for the capture of the entire volume of emitted gas. Gas compositions from cell experiments are usually measured using a gas chromatograph (GC), which is typically more accurate than measurements taken from exhaust hoods during module and unit testing.

5.1 Cell Test

The system under consideration is comprised of Xiamen Hithium Energy Storage Technology Co., Ltd LFP71173207/314Ah cells, which are 314 Ah lithium-ion LFP cells [4]. This cell was tested using the UL 9540A method. The results are given in the UL (Changzhou) Quality Technical Service Co., LTD report 4791072813 dated 2/27/2024. Figure 6 shows a cell that has been prepared for testing.

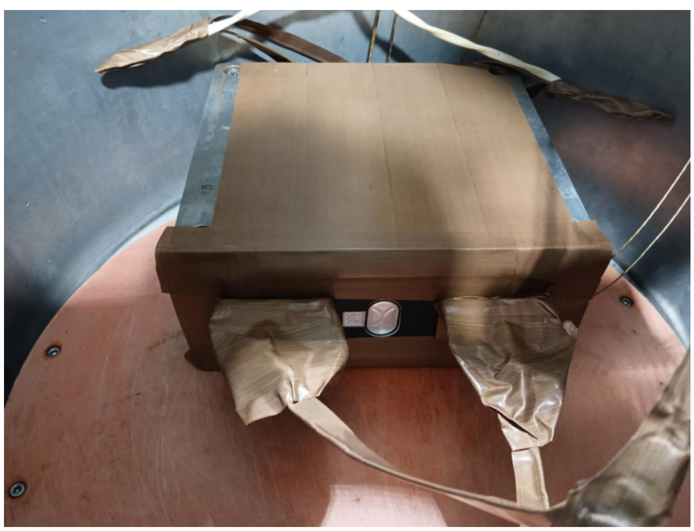


Figure 6: A Xiamen Hithium Energy Storage Technology Co., Ltd LFP71173207/314Ah cell prepared for testing. This image was taken from the UL 9540A cell-level test report [4].

For UL 9540A testing, the LFP71173207/314Ah cells were heated until failure occurred. Cell details and results from UL 9540A testing are provided in Table 2.

Table 2: Key cell properties from the UL 9540A cell test [4].

Parameter	Value
Cell Manufacturer	Xiamen Hithium Energy Storage Technology Co., Ltd
Cell Model	LFP71173207/314Ah
Cell Chemistry	LFP
Cell Nominal Voltage	3.2 V
Cell Capacity	314 Ah
Volume of Gas Released	171.2 L
Lower Flammability Limit (LFL) at ambient temperature	6.91%
Lower Flammability Limit (LFL) at venting temperature	5.9%
Burning Velocity (Su)	62.87 cm/s
Maximum Pressure (P_{max})	101.42 psig

The UL 9540A cell report showed that the cells go into thermal runaway and release a mixture of flammable gases when heated externally until failure. The vent gas composition from the UL 9540A cell report is listed in Table 3.

Table 3: The gas composition from the UL 9540A cell test [4]. Model Volume Percent will be addressed in Section 6 later in this document.

Name	Formula	Experimental Volume Percent	Model Volume Percent
Carbon Monoxide	CO	14.507	14.508
Carbon Dioxide	$CO2$	23.000	23.002
Hydrogen	$H2$	45.167	45.171
Methane	$CH4$	4.868	4.868
Acetylene	$C2H2$	0.148	0.000
Ethylene	$C2H4$	1.804	1.804
Ethane	$C2H6$	0.805	0.805
Propene	$C3H6$	2.256	0.000
Propane	$C3H8$	1.379	9.842
C4 Total	$C4H10$	2.029	0.000
C5 Total	$C5H12$	0.447	0.000
C6 Total	$C6H14$	0.021	0.000
C7 Total	$C7H16$	0.004	0.000
Benzene	$C6H6$	0.018	0.000
Toluene	$C7H8$	0.001	0.000
Dimethyl Carbonate	$C3H6O3$	3.340	0.000
Ethyl Methyl Carbonate	$C4H8O3$	0.198	0.000

5.2 Module Test

The Xiamen Hithium Energy Storage Technology Co., Ltd cells are located inside of modules with model number LM010401-A. A module was also tested using the UL 9540A method, and the results can be found in TUV Rheinland (Shenzhen) Co., Ltd. test report CN23XXY9 003 dated 5/11/2024. Each module contains 104 cells in a 2P52S configuration [5]. Multiple thermocouples were attached as seen in Figure 7.

Figure 7: A module prepared for the UL 9540A test. This image was taken from the UL 9540A module-level test report [5].

A heater was placed on cell #1-10, which was chosen as the initiating cell due to its central location within the module. The temperature time history for the test is shown in Figure 8. A diagram of the module construction, the location of the initiating cell, and thermocouple locations can be seen in Figure 9.

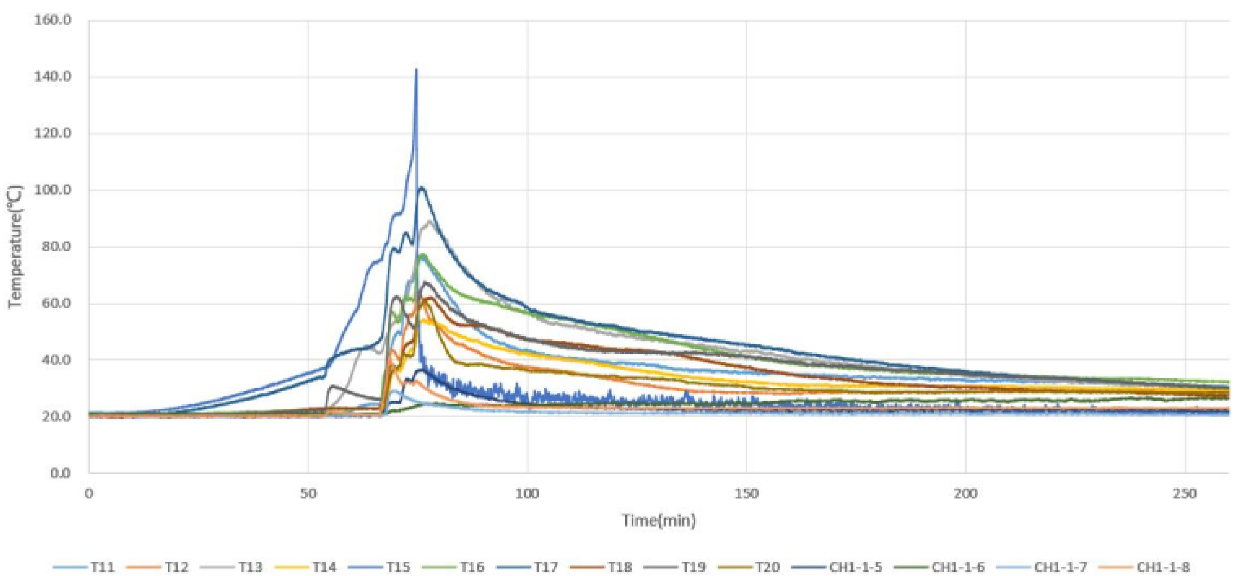


Figure 8: The temperature time history from the UL 9540A module test. This image taken was from the UL 9540A module-level test report [5].

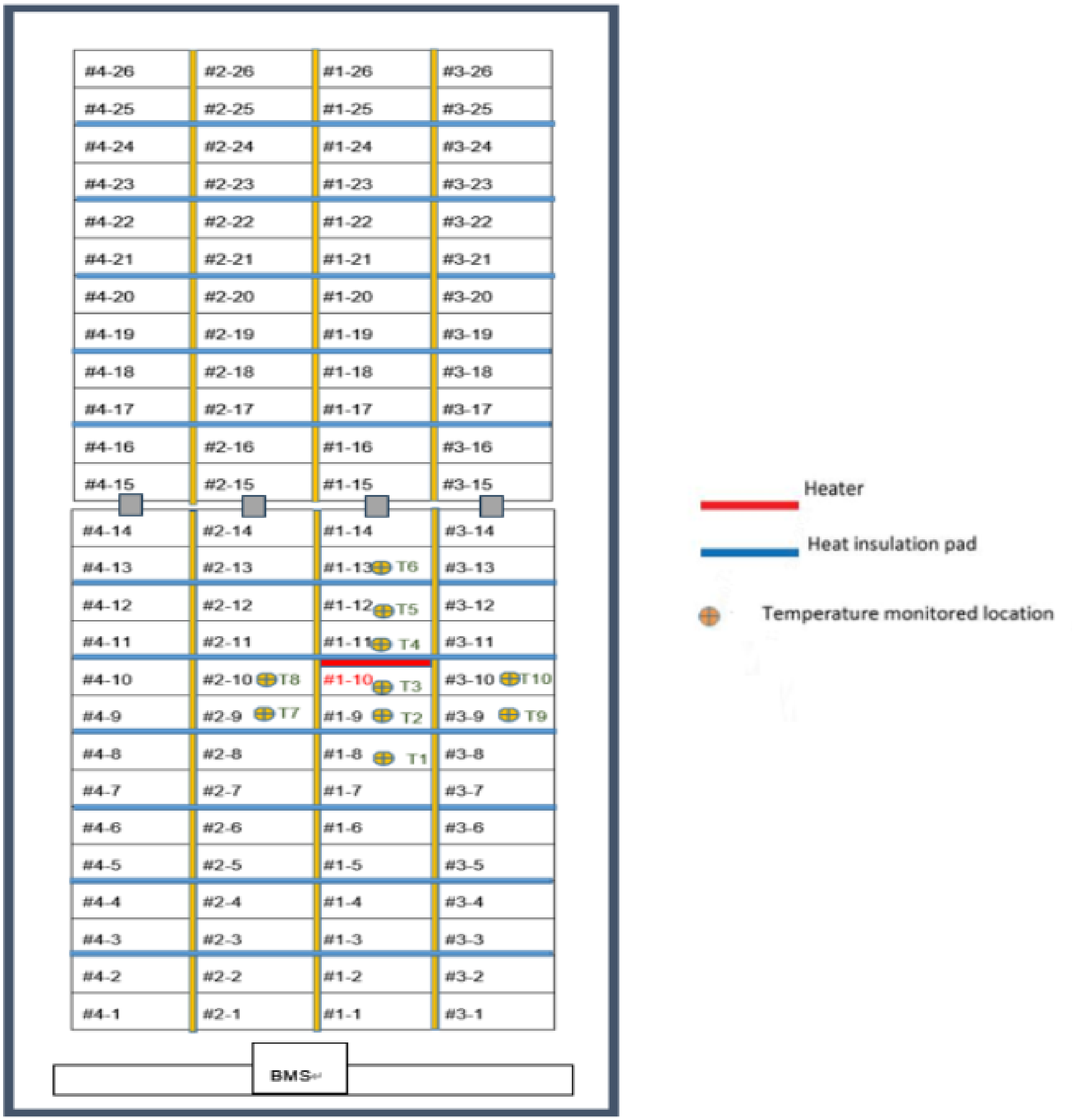


Figure 9: A diagram of the module setup for the UL 9540A test. This image was taken from the UL 9540A module-level test report [5].

The initiating cell was heated until thermal runaway occurred. Thermal runaway propagated to an adjacent cell, cell #1-9, making two cells in total that failed in thermal runaway [5]. Sparks, flying debris, and external flaming were not observed during the test. Figure 10 shows the internal contents of the module after the test.

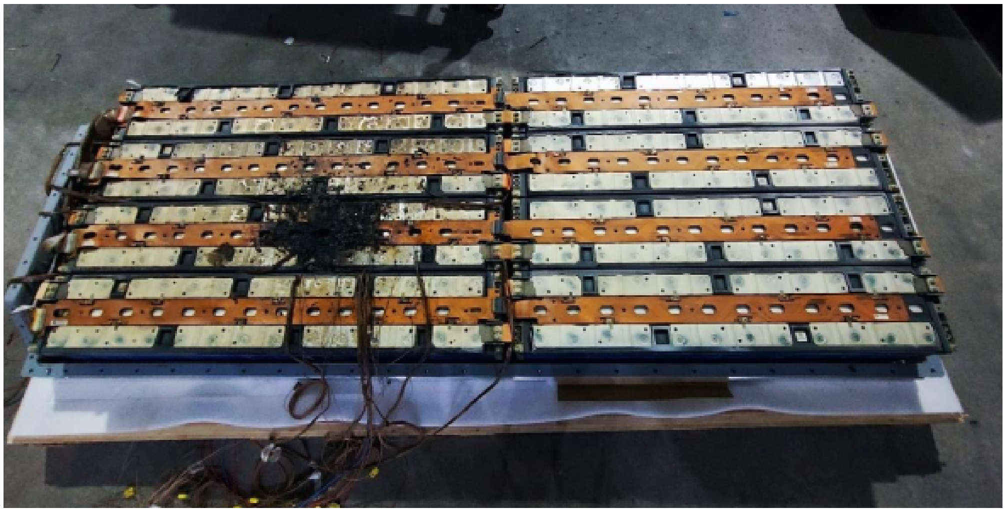


Figure 10: The internal contents of the module after the UL 9540A test. This image was taken from the UL 9540A module-level test report [5].

5.3 Unit Test

The UL 9540A unit test for unit model LC083502 is described in TUV Rheinland (Shenzhen) Co., Ltd. report CN244DBX 001 dated 4/26/2024. In this test, a unit comprised of 8 modules was tested. The unit contained 832 individual cells [6]. The initiating module was configured identically to the module test. This module was then inserted into a full unit, which was placed in proximity to walls and a target unit. The configurations of the initiating unit and target unit are shown in Figure 11, a diagram of the test setup is shown in Figure 12, and a picture of the initiating unit is shown in Figure 13.

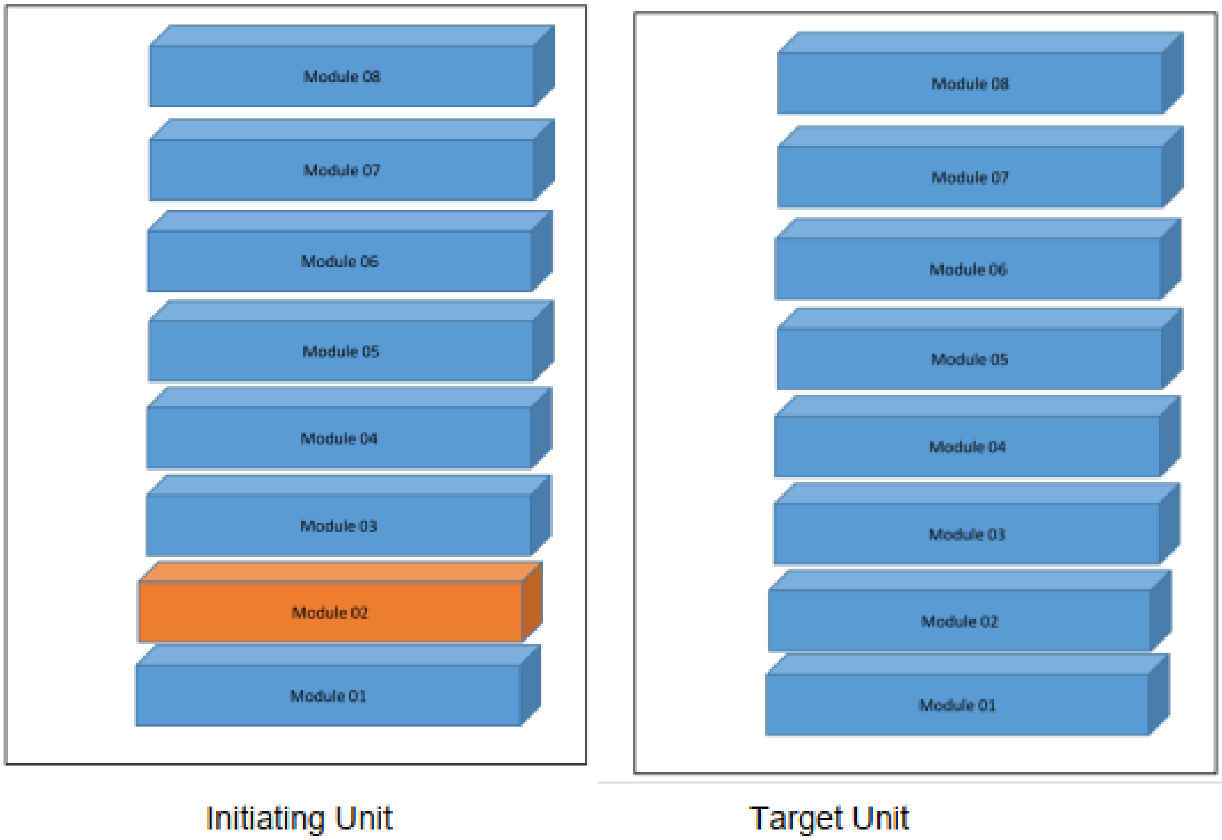


Figure 11: Two units with the initiating unit and target unit labeled. The initiating module is shown in orange. This image was taken from the UL 9540A unit-level test report [6].

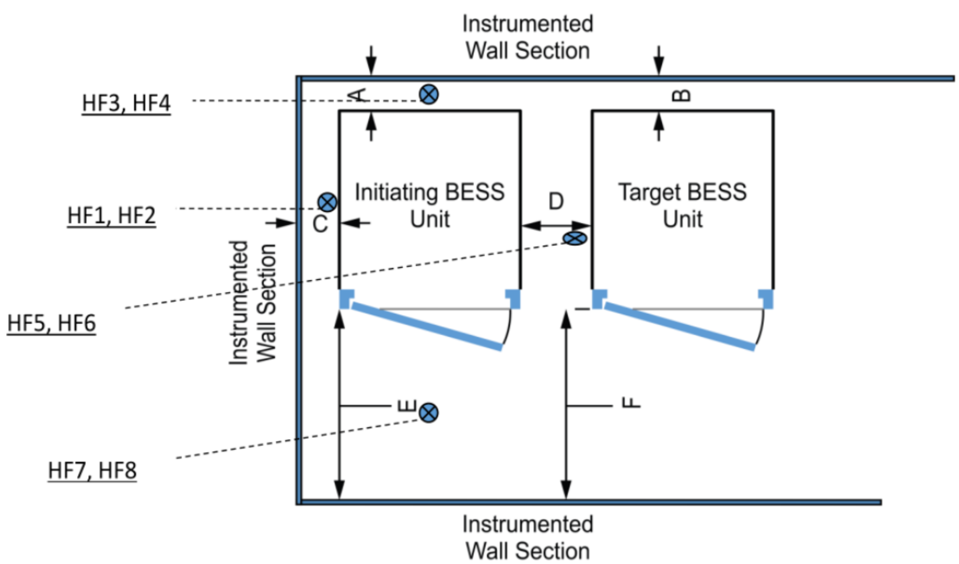


Figure 12: A diagram of the unit test setup. This image was taken from the UL 9540A unit-level test report [6].

Figure 13: A picture of the unit test setup. This image was taken from the UL 9540A unit-level test report [6].

Thermal runaway was initiated by activating the heater on Cell #1-10 in the initiating module. Once thermal runaway began, the power to the heater was disconnected. Thermal runaway then propagated to an adjacent cell, cell #1-9, making a total of two failed cells inside the initiating module [6]. Thermal runaway did not propagate outside of the initiating module to other modules or to other units. No sparks, flaming, or flying debris were observed.

6 Fire and Toxicity Modeling

Hazard Dynamics used data from the UL 9540A test reports to conduct plume modeling for a number of different failure scenarios. These models included cases of varying wind conditions, differing levels of failure severity, and with or without burning.

Two different heat release rates (HRR) were used to represent two different sizes of fire. The large HRR of 15 MW represents a full enclosure burning. This value was calculated using cell and module information from the UL 9540A cell and module tests [5] [4]. In calculating the peak HRR used for the model, it was assumed that all cells and modules burned over the course of four hours (half an hour ramp up, steady burn for three hours, and half an hour ramp down). Flaming propagation between adjacent enclosures was not modeled as available UL 9540A test data did not demonstrate propagation between modules inside of a unit or between units. The small HRR of 1.5 MW was taken to be 10% of the large fire. This HRR was used to evaluate the consequences of a smaller fire in which the entire enclosure does not burn.

The non-fire scenario models the release of lithium-ion battery vent gas from a segment in the absence of burning. This scenario considers gas release without an active ventilation system. A gas release rate of 0.00114 kg/s was calculated using the overall time cells entered into thermal runaway during the module-level test, the amount of gas released by a single cell during the cell-level test, and the number of cells failed during the module-level test [5] [4]. The calculation can be found in the appendix of this report. This gas release rate approximates the average release rate expected from two failing cells as demonstrated in the module-level test. Actual gas release rates may be slightly above or below this value during portions of the thermal runaway process.

Each scenario assumes a steady-state release and was modeled for 300 seconds. The scenarios are summarized in Table 4. The wind speeds used in the models will be discussed in Section 6.1.

Table 4: Hillman Energy Center plume model scenarios.

Name	Wind Speed (m/s)	Mass Release Rate (kg/s)	HRR (MW)
Gas release with low wind	1.5 m/s	0.00114 kg/s	No Fire
Large fire with low wind	1.5 m/s	0.763 kg/s	15 MW
Large fire with high wind	10 m/s	0.763 kg/s	15 MW
Small fire with low wind	1.5 m/s	0.0763 kg/s	1.5 MW
Small fire with high wind	10 m/s	0.0763 kg/s	1.5 MW

For modeling purposes, the most significant components which account for more than 95% of the gas are modeled in the non-fire gas release mixture, while minor hydrocarbon elements are approximated as propane. The volume percents used in the model can be found in column four of Table 3.

6.1 Model Setup

Computational fluid dynamics (CFD) models of possible CO and VOC exposure from battery fire plumes were created using Fire Dynamics Simulator (FDS) version 6.9.1. Fire Dynamics Simulator is a CFD software developed by the National Institute of Standards and Technology (NIST) for fire modeling. The code solves the Navier-Stokes equations using a large-eddy-simulation (LES) approach and is mainly intended for low-speed flows with an emphasis on smoke and heat transport from fires. The code has been extensively validated for a variety of scenarios involving fire, smoke, gas dispersion, and other transport phenomenon. The model uses grid sizes ranging from 0.25 m (9.8 in) to 2 m (6.6 ft) to capture both the flow near the source (starting 2 m from the enclosure) as well as the dispersion over a large flat downwind area up to 320 m (1050 ft) away from the source as shown in Figure 14.

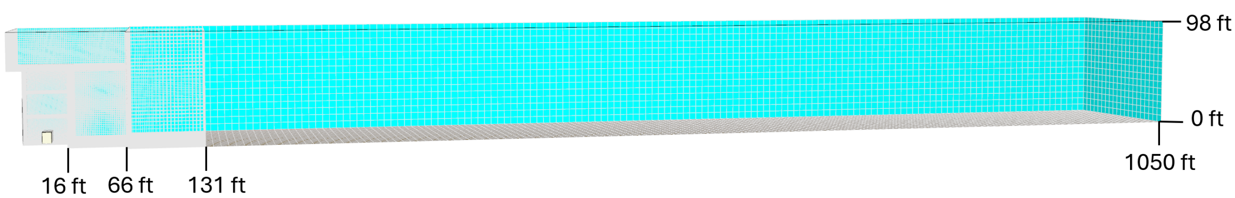


Figure 14: The model with the grid displayed. The grid varies in size from 0.25 m near the unit to 2 m starting 40 m away from the unit. The distances shown are measured from the front of the enclosure.

The EPA Risk Management Program recommends using a wind speed of 1.5 m/s (3.4 mph) and atmospheric stability class F conditions (stable atmosphere) for worst-case plume analysis for accidental chemical releases [13]. This wind speed was used in the model as well as the 99th percentile wind speed for the Hillman Energy Center site, which is roughly 10 m/s or 22 mph (see Section 4.1.1). High winds may act to partially overcome the upward tendency of a fire plume.

The results presented here approximate worst-case results based on the wind speeds modeled and using stable atmospheric conditions with an Obukhov length of 350 meters. Because the Hillman Energy Center site is in an area with clumps of trees, residential buildings, and commercial businesses, a Davenport-Wieringa roughness length of 0.5 m was used.

The wind speeds used in the models are intended to be worst-case. Therefore, results from other wind speeds are expected to be bounded by the wind speeds used. Likewise, modeling a stable atmosphere, in which released gases tend to stay near ground-level, is considered worst-case. Stable conditions may include fog, because the stability prevents vertical movement of the moist air near the ground. The moisture in fog conditions is not expected to make a plume resulting from battery vent gas release or a fire any worse. Rain during a BESS failure incident is expected to result in a less severe plume than modeled because the falling water could encourage mixing and dispersion over a wider area.

6.2 Results

Model results were collected for battery vent gas concentrations (non-fire scenario) and combustion product concentrations (fire scenarios). The gas concentration of interest was the concentration at 2 m (6.6 ft) above ground level. This corresponds to the concentration that people would experience when standing on level ground near an incident. Figure 15 shows the average vent gas and combustion product gas concentrations at 2 m (6.6 ft) above ground level at different distances downwind of the unit. Figure 15 shows that these concentrations stay low for the non-fire scenario and for the fire scenario with low wind and small fire conditions. For the high-wind fire scenarios, the force of the wind suppressed the thermal buoyancy of the hot gas plume. This lead to a higher concentration of product gas near the ground level. The maximum concentrations were observed in the large fire, high wind scenario. Notably, the concentrations resulting from the small fire, high-wind scenario were of a similar magnitude to those from the large fire, low-wind scenario. The modeled high wind speed was 10 m/s (22 mph), which is the 99th percentile wind speed for the Hillman Energy Center site. However, since CO and VOCs are only a fraction of the total battery vent gas or combustion products, their concentrations would be a fraction of these values. As the battery vent gas has a lower flammability limit (LFL) of 6.91% by volume (69100 ppm), the concentration of battery gas does not achieve a flammable condition beyond 2 m (6.6 ft) of the BESS unit.

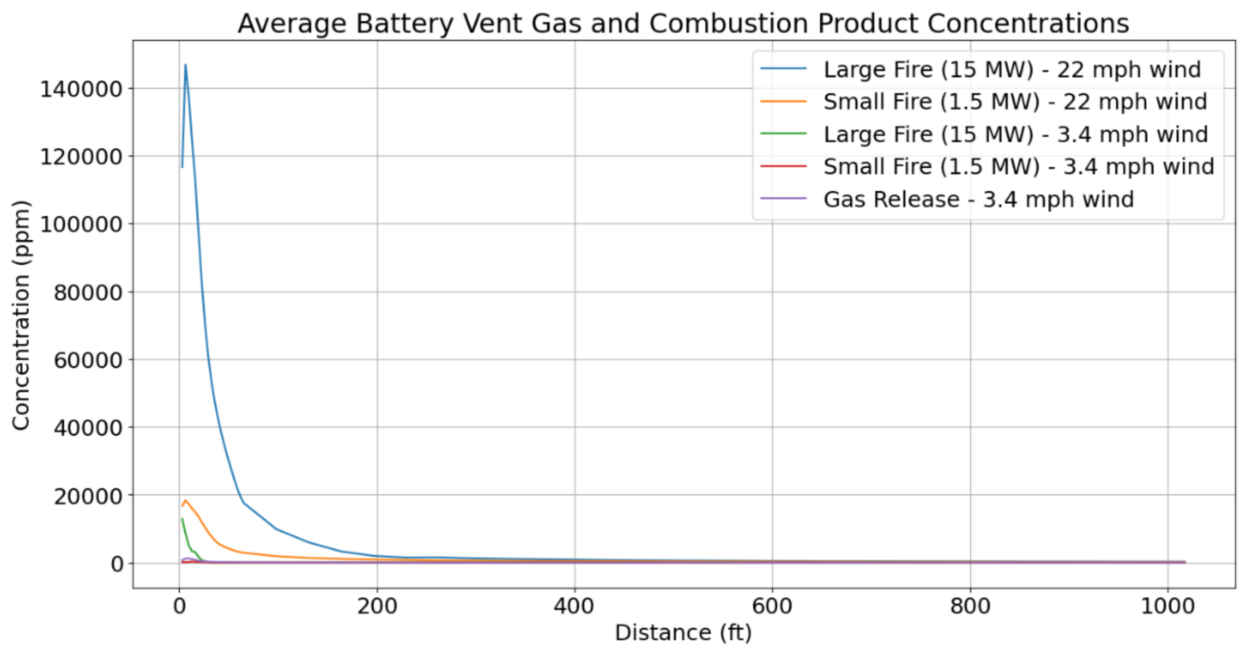


Figure 15: The average combustion products concentration 2 m (6.6 ft) above ground level versus the downwind distance for different model scenarios.

Battery gas concentrations were very small away from the battery enclosure for the non-fire scenario, as shown in Figure 16.

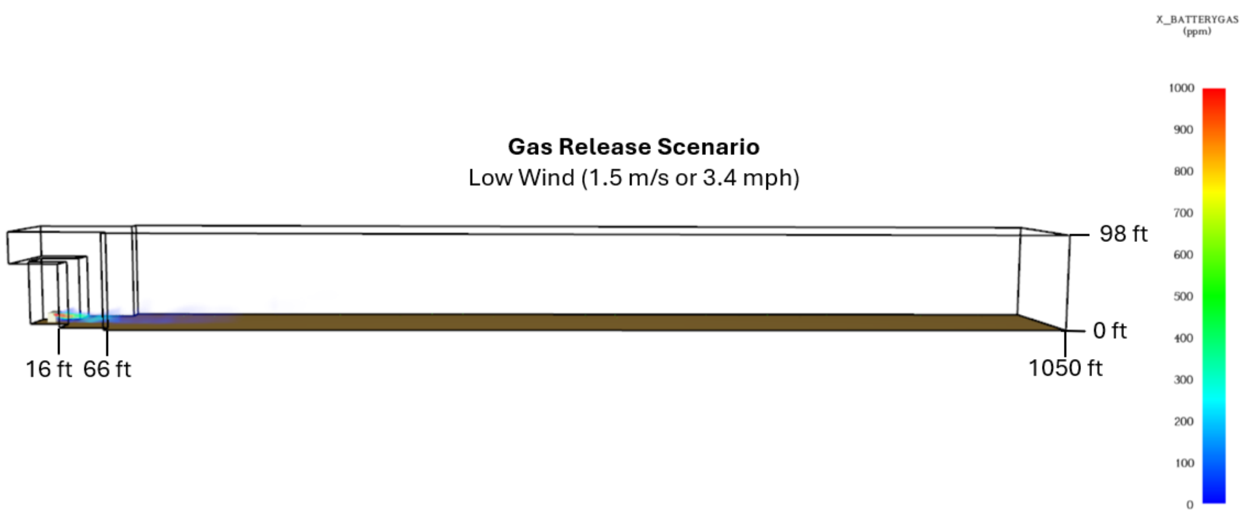


Figure 16: The model for a non-fire scenario with low wind speeds. X_BATTERYGAS is the concentration of battery vent gas in ppm. The distances shown are measured from the front of the enclosure.

The fire scenarios with greater wind speeds resulted in higher concentrations of combustion products 2 m (6.6 ft) above ground level. The heat from fire conditions makes gases more buoyant such that they rise away from the ground. In most common wind conditions, fire product concentrations are low at ground level. However, under conditions of high wind, this buoyant effect may be partially overcome. The scenarios with both fire and high winds yielded the highest gas concentrations near ground level at the greatest distances. Figure 17 shows the model with a full unit fire at high wind speeds. This figure shows that the hot combustion products do not rise immediately due to high wind conditions, but they do rise gradually. Additionally, mixing occurs as the combustion products move away from the enclosure. In contrast, Figure 18 shows that the combustion products rise immediately under low wind conditions.

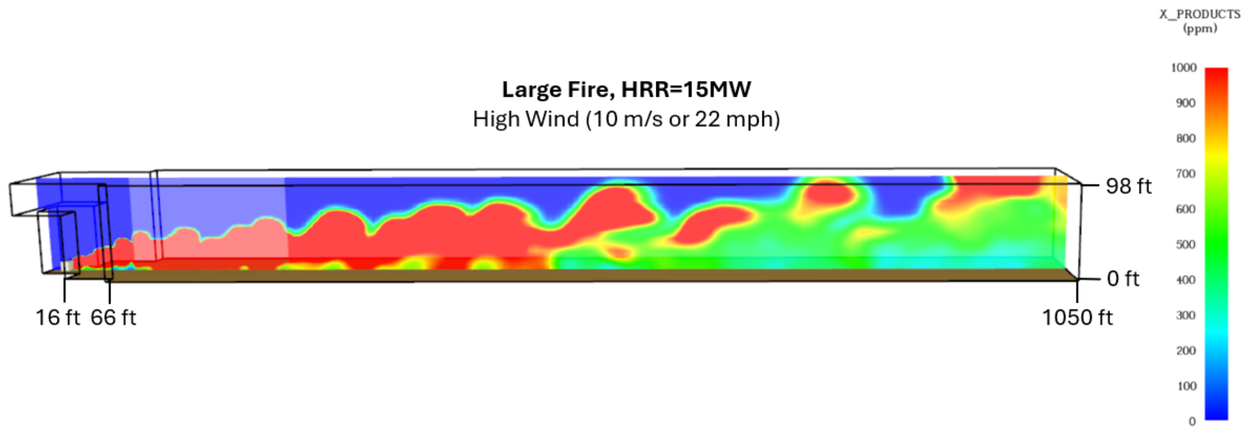


Figure 17: The model of a full unit fire with high wind conditions. In this scenario, the combustion products do not rise immediately due to high wind conditions, but they do rise over time while also mixing with air. X_PRODUCTS is the concentration of combustion products in ppm. The distances shown are measured from the front of the enclosure.

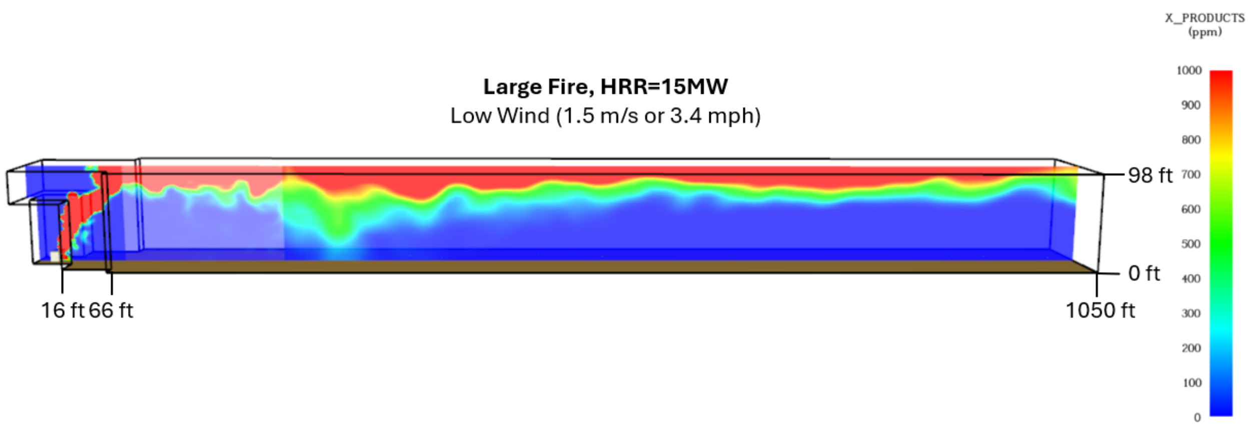


Figure 18: The model of a full unit fire with low wind conditions. In this scenario, the combustion products rise immediately and stay elevated for long distances. X_PRODUCTS is the concentration of combustion products in ppm. The distances shown are measured from the front of the enclosure.

Figure 19 shows that for a smaller fire with high winds, the combustion products stay near ground level for some distance before mixing occurs. In low wind conditions, combustion products for a small fire also rise but to a lesser degree than for a large fire scenario as shown in Figure 20.

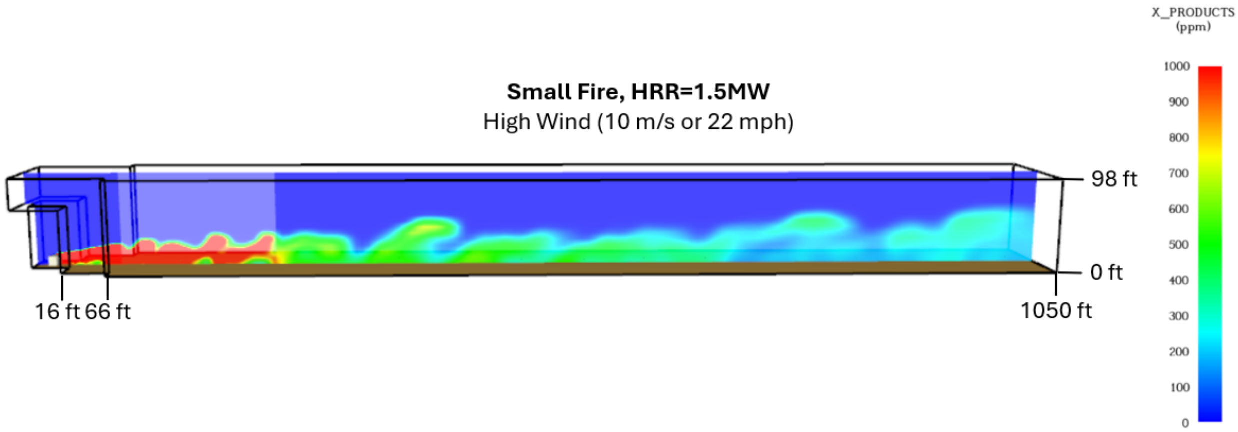


Figure 19: The model of a small fire with high wind conditions. In this scenario, the buoyant effects of the hot gas are partially overcome by the high wind such that the combustion products stay near ground level until mixing occurs. X_PRODUCTS is the concentration of combustion products in ppm. The distances shown are measured from the front of the enclosure.

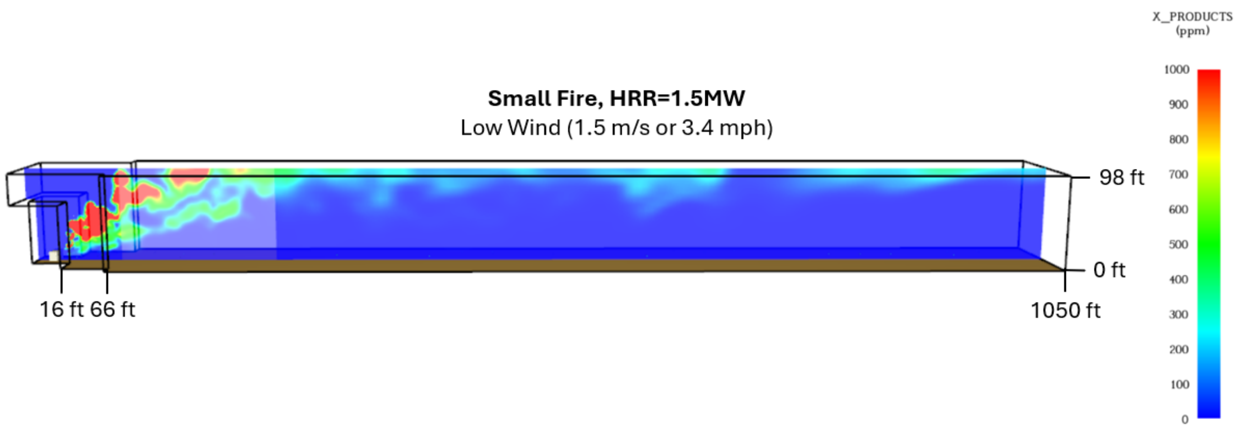


Figure 20: The model of a small fire with low wind conditions. In this scenario, combustion products rise to a lesser degree than in the large fire scenario. X_PRODUCTS is the concentration of combustion products in ppm. The distances shown are measured from the front of the enclosure.

Although multiple toxic gases may be components of battery vent gas, carbon monoxide (CO) is generally the most abundant toxic gas of concern that is regularly reported as part of UL 9540A testing. The UL 9540A cell test report for the Hithium Block listed the carbon monoxide concentration as being 14.507%. However, it is unclear what concentration of carbon monoxide may persist through a fire. The carbon monoxide concentration in burned gas is likely to be much lower than in the battery gas as CO is flammable. Carbon monoxide due to incomplete combustion from the fire can also vary depending on the burning environment. Consequently, Hazard Dynamics estimated what amount of carbon monoxide might be present during a fire event using knowledge from work with many battery systems. The CO production was assumed to be 2% of the combustion products. This estimation was based on the measured combustion product concentration from the FDS models. The average carbon monoxide concentration over the 300 m (984 ft) model domain for both the gas release and fire scenarios is shown in Figure

21. The IDLH (Immediately Dangerous to Life and Health) level for carbon monoxide is 1200 ppm, the AEGL-3 (life-threatening health effects) level for a 30-minute exposure is 600 ppm, and the AEGL-2 (serious health effects) level for a 30-minute exposure is 150 ppm. The EPA does not provide an AEGL-1 (temporary irritation) concentration for carbon monoxide. Model results show that the carbon monoxide concentration may be immediately dangerous to life and health (above the IDLH level) up to approximately 9.1 m (29.9 ft), cause life-threatening effects (exceed the AEGL-3 level) up to approximately 15.3 m (50.3 ft), and cause serious health effects (exceed the AEGL-2 level) up to approximately 36 m (118 ft) from the burning enclosure.

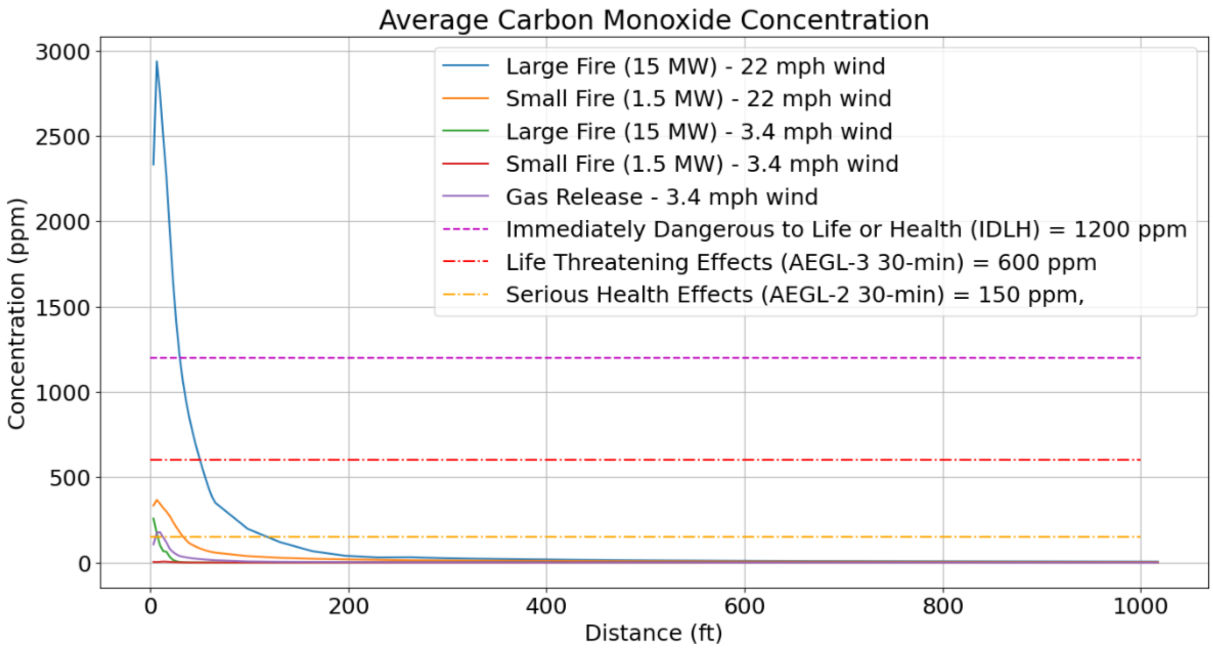


Figure 21: The modeled average carbon monoxide concentrations as a function of distance for different combustion product release scenarios. From this chart, we see that the carbon monoxide concentration may be immediately dangerous to life and health up to approximately 29.9 ft from the unit, may cause life-threatening effects up to approximately 50.3 ft from the unit, and may cause serious health effects up to approximately 118 ft from the unit in a large fire scenario with high winds. The high wind speed modeled was 22 mph, which is the 99th percentile wind speed for the Hillman Energy Center site.

Typically, hydrocarbons such as benzene and toluene are the only toxic gas concentrations other than carbon monoxide that are measured as part of the UL 9540A testing process. These do not present significant toxicity hazards compared to carbon monoxide, as their concentrations in battery gas are usually orders of magnitude less while having generally higher AEGL concentrations than CO. For the Xiamen Hithium Energy Storage Technology Co., Ltd cells, the benzene and toluene concentrations are 0.018% and 0.001%, respectively.

7 Conclusion

Of the measured toxic gas species for which test data is available, carbon monoxide is of primary concern due to its comparatively high concentrations and toxicity. Carbon monoxide has an IDLH (immediately dangerous to life and health) level of 1200 ppm, an AEGL-3 (life-threatening health effects) level for a 30-minute exposure of 600 ppm, and an AEGL-2 (serious health effects) level for a 30-minute exposure of 150 ppm. No AEGL-1 level is provided for CO. Carbon monoxide may constitute up to 14.507% of the unburned battery vent gas based upon the provided UL 9540A cell-level report. Carbon monoxide concentrations 2 m (6.6 ft) from ground level were measured by FDS for the non-fire scenario and calculated using modeled fire product concentrations and typical carbon monoxide levels present during lithium-ion battery fires for the large and small fire scenarios. The modeled average carbon monoxide concentrations may be immediately dangerous to life and health (exceed the IDLH level) up to 29.9 ft, cause life-threatening health effects (exceed the AEGL-3 level) up to 50.3 ft, and cause serious health effects (exceed the AEGL-2 level) up to approximately 118 ft from the unit in a large fire scenario with high winds. The modeled high wind speed of 10 m/s (22 mph) is the 99th percentile wind speed at the Hillman Energy Center site. Under high wind and small fire conditions, model results show that the carbon monoxide concentration never exceeds the IDLH or AEGL-3 levels, but it can cause serious health effects (exceed the AEGL-2 level) up to approximately 33.5 ft from the burning enclosure. Under low wind and non-fire gas release conditions, model results show that the carbon monoxide concentration never exceeds the IDLH or AEGL-3 levels, but it can cause serious health effects (exceed the AEGL-2 level) up to approximately 12.8 ft from the burning enclosure. Under low wind and large fire conditions–model results show that the carbon monoxide concentration never exceeds the IDLH or AEGL-3 levels, but it can cause serious health effects (exceed the AEGL-2 level) up to approximately 7.6 ft from the burning enclosure. No toxicity consequences were present for the modeled scenario with low wind and small fire conditions. Volatile organic compound release quantities are too small to exceed IDLH or AEGL levels at any distance from the unit.

Planning documents [1] and publicly available maps indicate that the area surrounding the Hillman Energy Center site includes a house approximately 80 ft away, several commercial buildings as close as 157 ft, and a church approximately 0.7 mi away. Based on the model results and the prevailing wind direction at the site, it is possible that carbon monoxide could cause serious health effects (reach AEGL-2 levels) at the nearest house, but it is unlikely that other nearby buildings will experience toxic levels of carbon monoxide in the event of a single BESS unit experiencing a failure event (see Figure 2).

Given the potential risk of toxicity hazards during failure scenarios of the BESS, appropriate emergency response protocols should be considered and developed in collaboration with local emergency personnel. During an incident, site conditions may change and should be monitored throughout the incident. Changes in conditions may require appropriate adjustment to response measures. Additional discussion of emergency response protocols may be provided in a separate emergency response guideline document. Figure 22 shows the areas that could have toxic carbon monoxide gas concentrations exceeding the IDLH level (immediately dangerous to life and health), the AEGL-3 level (life-threatening health effects), and the AEGL-2 level (serious health effects) based on the worst-case modeled scenarios for high winds at the Hillman Energy Center project site. These distances were measured from the outermost BESS enclosures.

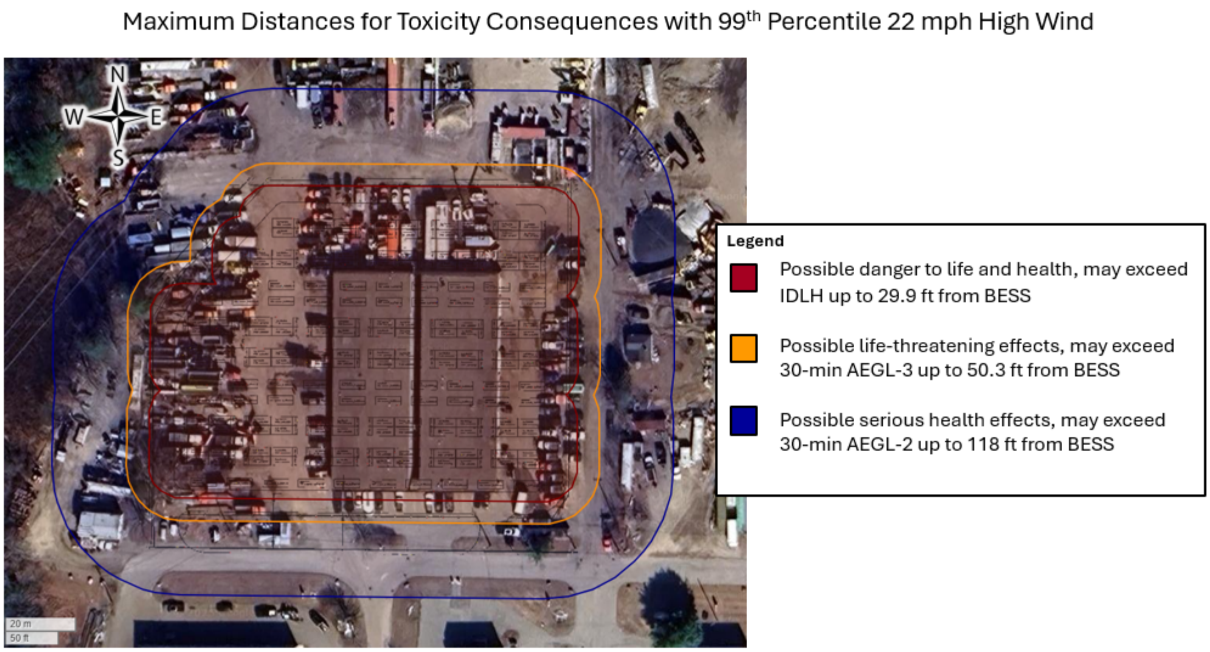


Figure 22: Satellite imagery of the immediate site surroundings with overlaid areas containing possible IDLH, AEGL-3, and AEGL-2 levels of CO with large fire conditions and steady 10 m/s (22 mph) wind, which is the 99th percentile wind speed for the Hillman Energy Center site. Under low wind and large fire conditions, high wind and small fire conditions, and gas release conditions, modeled scenarios reached AEGL-2 levels. No CO toxicity consequences were present for the modeled scenario with low wind and small fire conditions. This image was produced using Open Street Map and Google Maps.

The buffers in Figure 22 show the maximum modeled distances for critical concentrations of CO in all possible wind conditions. In reality, the wind will only come from one direction at a time, so a plume resulting from BESS failure will travel predominantly in one direction. Figure 23 shows CO concentrations from a modeled plume for a high wind coming from the prevailing wind direction, which is south-southwest for the Hillman Energy Center site.

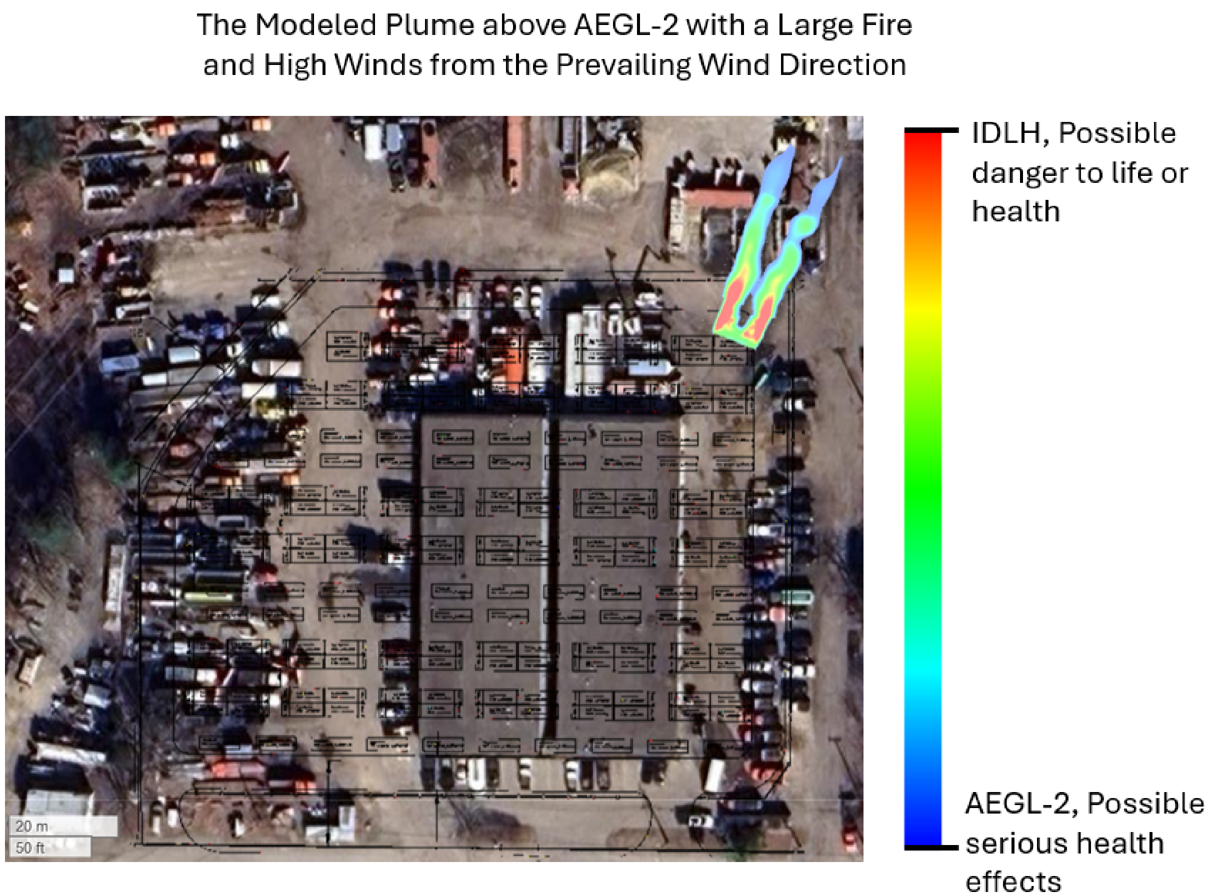


Figure 23: Satellite imagery of the immediate site surroundings with overlaid CO concentrations from a plume that was modeled with 22 mph wind from the south-southwest. This image was produced using Open Street Map and Google Maps.

The analysis in this report assumes that only one battery unit fails or burns at a time. There are several conditions that may lead to worse consequences than those predicted by this model. These conditions include, but are not limited to, thermal runaway propagation exceeding the measured release rate and involvement of multiple units.

8 Limitations

- The study presented in this report is intended for use by client to assist with their decision making related to toxicity risks due to plume transport and evolution from Lithium-ion Battery Energy Storage Systems (BESS). This study specifically does not address other energy storage designs, feasibility of other toxic gas mitigation methods, or compliance to local codes and standards. The scope of the analysis was strictly limited to collection of data relevant to scope.
- The scope of services performed may not adequately address the needs of other users of this report, and any re-use of this report is at the sole risk of the user. This study is based on observations and information available at the time of the analysis. No guarantee or warranty as to future life or performance of any reviewed condition is expressed or implied.

- In the analysis, we have relied on documentation, including but not limited to facility design, BESS design, and other siting documents provided by the client. We cannot verify the correctness of this data and rely on the client for their accuracy. Although we have exercised usual and customary care in the conduct of this analysis, the responsibility for the design and manufacture of the product remains fully with the client.
- The methodology forming the basis of the results presented in this report is based on mathematical modeling of physical systems and data from third parties. Given the nature of these evaluations, significant uncertainties are associated with the various computations. These uncertainties are inherent in the methodology and subsequently in the generated results. Furthermore, the assumptions adopted do not constitute the exclusive set of reasonable assumptions, and use of a different set of assumptions or methodology could produce materially different results.

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A Appendix

1 Gas Release Rate

$$t_{propagation} = 277.50000 \text{ second}$$

$$V_{gascell} = 0.17120 \text{ meter}^3$$

$$n_{cells} = 2$$

$$r_{gasrelease} = V_{gascell} \cdot \frac{n_{cells}}{t_{propagation}} = 0.17120 \text{ meter}^3 \cdot \frac{2}{277.50000 \text{ second}} = 0.00123 \frac{\text{meter}^3}{\text{second}}$$

$$\rho_{gas} = 0.92319 \frac{\text{kilogram}}{\text{meter}^3}$$

$$G = r_{gasrelease} \cdot \rho_{gas} = 0.00123 \frac{\text{meter}^3}{\text{second}} \cdot 0.92319 \frac{\text{kilogram}}{\text{meter}^3} = 0.00114 \frac{\text{kilogram}}{\text{second}}$$

B Revisions

Table 5: Document revision history.

Revision	Date	Description
0.1	September 19 2025	Initial draft version submitted to client for review.
0.2	September 30 2025	Edited draft version submitted for client review.
0.3	October 15 2025	Updated draft with titles of figures changed
1.0	October 27 2025	Final issued