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OFFSITE CONSEQUENCE ANALYSIS

VISTRA MORRO BAY BATTERY ENERGY STORAGE SYSTEM (BESS) PROJECT

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OFFSITE CONSEQUENCE ANALYSIS
VISTRA MORRO BAY BESS PROJECT

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Prepared by	**Shari Beth Libicki, Ph.D.** **Biljana Cosic, Ph.D.** **Shirley Lam, Ph.D.** **Volodymyr Shatokha, Ph.D.** **Farzan Oroumiyeh, Ph.D.**
Reviewed by	**Ehsan Haghighi, Ph.D.**

EXECUTIVE SUMMARY

This Offsite Consequence Analysis (OCA) evaluates the potential risks to the public due to an unexpected fire event at Vistra's proposed 600 megawatt (MW) battery energy storage system (BESS) project in Morro Bay, California. To provide a conservative analysis, the OCA assumes a maximum credible fire event occurs under conditions designed to over-predict impacts. The analysis uses models recommended by regulators, such as the U.S. Environmental Protection Agency (EPA).

This OCA is intended to aid the City of Morro Bay's (City) consideration of Vistra's proposed BESS project and to provide information to the community. As detailed in this OCA, Vistra's proposed BESS does not present any significant health and safety risk to the public.

Siting decisions for proposed projects often involve consideration of potential health and safety impacts. BESS facilities have been installed around the world and this OCA has taken into consideration the performance history of BESS facilities across jurisdictions. For example, New York City has analyzed the siting of BESS facilities and approved their installation in urban areas (e.g., residential, commercial). Further, fire codes and industry safety standards for BESS facilities have been updated over time, including California's passage of Senate Bill 38 in 2023, which requires appropriate emergency response plans and other safety requirements to further mitigate risks for BESS facilities.

To prepare this OCA, we reviewed literature on BESS safety and fire incidents from leading scientists, battery experts, and regulatory bodies such as UL Solutions, Electric Power Research Institute (EPRI), Pacific Northwest National Laboratory (PNNL), the California Public Utilities Commission (CPUC) and Det Norske Veritas (DNV). We also reviewed analyses of historic BESS thermal events to evaluate their scale, emissions, and impacts. We did not identify any prior BESS thermal event that resulted in significant offsite impacts or injuries.

The proposed BESS facility analyzed by this OCA would be installed on the former tank farm of the decommissioned Morro Bay Power Plant. As set forth in the Draft Environmental Impact Report (DEIR) released by the City on March 11, 2024, the proposed project involves two basic configurations: three buildings or 174 separate enclosures (containers). This OCA evaluates both scenarios.

The BESS would use lithium-ion batteries (LiBs), which are found in myriad consumer products (e.g., phones, computers). Under normal operating conditions, LiBs produce no emissions and are safe. However, in some situations LiBs may fail and then overheat. If the overheating is not interrupted by mitigation measures, the LiB may enter "thermal runaway," a process through which the battery overheats beyond its capacity to dissipate heat. If thermal runaway is not controlled by safety systems, a single battery could catch fire, and that fire could spread to other adjacent batteries. Although redundant safety systems are available to prevent this multi-step process from occurring, this OCA assumes that such systems fail.

For purposes of modeling, the analysis determined that the maximum credible fire event presented by the proposed BESS is the combustion of one full block (building configuration) or one full enclosure (enclosures configuration) of batteries over a 24-hour period. As noted, this OCA conservatively assumes that during such an event all active control measures fail. However, the

OCA does consider passive design measures, such as thermal passivating layers between racks, walls, blocks, and enclosures, which are analogous to firewalls in a building. These passive design features are assumed to work as intended consistent with U.S. EPA guidance.

To derive the rate and amount of emissions generated during a fire event, we reviewed literature concerning emissions from battery fires. This OCA provides a conservative assessment of potential emissions (and therefore impacts) by using the highest reliable emission rate for each pollutant that was identified in the literature. As explained in Section 3 of this OCA, the primary hazardous pollutant associated with a BESS fire is hydrogen fluoride (HF), although we also evaluated other pollutants that may be emitted from plastics combustion in a fire event.

This OCA also makes a number of other conservative, impact-maximizing assumptions about the assumed fire event and its effects in order to evaluate impacts to the surrounding community. These assumptions include:

- That the fire occurs at a location closest to the nearest residence (~135 meters or ~440 feet away), which maximizes the concentrations at that residence;
- That the nearest residence is occupied and the resident(s) are outside at all times, which maximizes exposure concentrations and durations;
- Low wind speed, which maximizes concentrations at nearby residences due to reduced dispersal and atmospheric mixing;
- Low fire temperature, which results in reduced buoyancy (height) of emissions and higher concentrations at ground levels of nearby residences; and
- Source parameters (i.e., site and equipment configuration) that are designed to maximize concentrations from emissions.

After making these assumptions, we used EPA-approved dispersion models to calculate maximum expected concentrations at nearby residences. The OCA then compares these concentrations to two accepted guidelines on acute exposure: Acute Exposure Guideline Levels (AEGLs) and Emergency Response Planning Guidelines (ERPGs).

As discussed in Section 4 of this OCA, under both the buildings configuration and enclosures configuration, concentrations are expected to be well below the relevant AEGL and ERPG values for all relevant pollutants of concern. We note, however, that the expected concentrations associated with the enclosures configuration are slightly lower.

In sum, we conclude the proposed BESS project poses no significant health and safety risk to the community during a maximum credible fire event under worst-case conditions.

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Acronym or Abbreviation	Full Name or Spelling
AEGL	Acute Exposure Guideline Level
ALOHA	Areal Locations of Hazardous Atmospheres
Al	Aluminum
As	Arsenic
B	Boron
Ba	Barium
BESS	Battery Energy Storage System
Br	Bromine
C	Carbon
CH_3F	Fluoromethane
CH_4	Methane
C_2H_2	Acetylene
C_2H_4	Ethylene
C_2H_6	Ethane
C_2H_5F	Fluoroethane
C_2H_5OH	Ethanol
CH_3OCH_3	Dimethyl Ether
CH_3OCHO	Methyl Formate
CH_3OH	Methanol
C_3H_6	Propene
C_3H_8	Propane
C_4H_6	1,3-butadiene
C_6H_6	Benzene
$C_6H_5CH_3$	Toluene
C_8H_8	Styrene
C_8H_{10}	Xylene
Ca	Calcium
CAA	Clean Air Act
CalARP	California Accidental Release Program
CARB	California Air Resources Board
CFC	California Fire Code
CFR	Code of Federal Regulations
C°	Centrigrade or Celsius
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CPUC	California Public Utility Commission
Cl	Chlorine
Co	Cobalt
Cr	Chromium
Cu	Copper
DEC	Diethyl Carbonate
DMC	Dimethyl Carbonate

DOE	Department of Energy
DEIR	Draft Environmental Impact Report
EIA	U.S. Energy Information Administration
EMC	Ethyl Methyl Carbonate
EPRI	Electric Power Research Institute
ERPG	Emergency Response Planning Guideline
°F	Fahrenheit
F	Flourine
Fe	Iron
FTIR	Fourier-Transform Infra-Red
GW	Gigawatt
g	Gram
HAP	Hazardous Air Pollutants
H, H_2	Hydrogen
HCOH	Hydroxymethylene
H_3PO_4	Phosphoric Acid
HBr	Hydrogen Bromide
HCl	Hydrochloric Acid
HCN	Hydrogen Cyanide
HF	Hydrogen Fluoride
hr	Hour
ISC3	Industrial Source Complex dispersion model, version 3
I	Iodine
K	Potassium
Li	Lithium
LiB	Lithium-ion battery
LiF	Lithium Fluoride
LiFSI	Lithium Bis(fluorosulfonyl)imide
$LiPF_6$	Lithium Hexafluorophosphate
kg	Kilogram
m	Meter
Mg	Magnesium
mg	Milligram
Mn	Manganese
MW	Megawatt
MWh	Megawatt-hour
Mo	Molybdenum
Na	Sodium
NH_3	Ammonia
Ni	Nickel
NMC	Lithium Manganese Cobalt
NFPA	National Fire Protection Association
NOAA	National Oceanic and Atmospheric Administration
NO	Nitric Oxide
NO_2	Nitrogen Dioxide
NOx	Oxides of Nitrogen

O_2	Oxygen
OCA	Offsite Consequence Analysis
P	Phosphorous
PAC	Protective Action Criteria
PAHs	Polycyclic Aromatic Hydrocarbons
PF_3	Phosphorous Trifluoride
PH_3	Phosphine
PM	Particulate Matter
POF_3	Phosphoryl Fluoride
PVC	Polyvinyl Chloride
RH	Relative Humidity
RMP	Risk Management Program
RTO	Regional Transmission Organization
s	Second
SCREEN3	Screening level air dispersion model – version 3
S	Sulfur
Sb	Antimony
Si	Silicon
SiF_4	Silicon Tetrafluoride
Sn	Tin
Sr	Strontium
SO_2	Sulfur dioxide
SOC	State of Charge
THC	Total Hydrocarbons
Ti	Titanium
T_{MAX}	Maximum temperature
TVOC	Total Volatile Organic Compounds
US EPA	United States Environmental Protection Act
V	Vanadium
VOCs	Volatile Organic Compounds
W	Watt
Zn	Zinc
Zr	Zirconium

1. INTRODUCTION AND SCOPE OF WORK

1.1 Project Overview

The goal of this Offsite Consequence Analysis (OCA) Report is to assess the risks associated with Vistra's proposed 600 megawatt (MW) battery energy storage system (BESS) facility located at the Morro Bay Power Plant in Morro Bay, California. This OCA presents: a review of literature concerning battery fires, a discussion of the general causes of battery fires, and the potential air emissions from these events. This OCA also analyzes the potential offsite consequences of a fire at the proposed facility, including potential consequences under a maximum credible event scenario.

The proposed BESS project would be constructed following the completion of the environmental review and entitlement process, and only if all necessary approvals and permits are received. Project construction is expected to take 36 to 48 months. Upon completion, the BESS is projected to power approximately 450,000 homes when renewable resources are not available.

Proper design, construction, and operation of battery energy storage systems can greatly reduce the possibility of fires and can mitigate related risks. Battery energy storage technologies are rapidly evolving. California and regulatory agencies have taken steps to ensure that these facilities are constructed and operated in a manner that minimizes risks to human health and safety and the environment. However, as with many other industrial and energy facilities, it is not always possible to entirely eliminate the possibility that upsets may occur. This report therefore provides an analysis of risks concerning BESS upsets, with a focus on the impacts of a potential fire at the Morro Bay Power Plant site.

1.2 Project Description

1.2.1 Project Site and Location

The proposed Project would be located at the 107-acre Morro Bay Power Plant property located at 1290 Embarcadero, Morro Bay, California, south of State Route 1 (SR 1)/Cabrillo Highway (Project Parcel). The Project Parcel encompasses the inactive Morro Bay Power Plant, Lila Keiser Park, and the Marine Mammal Center operated by Pacific Wildlife Care.

The proposed project would involve the construction and operation of the proposed BESS and the remediation and demolition of the idled Morro Bay Power Plant. These activities will occur on a 43-acre subplot (Project Site) of the Project Parcel.

As further discussed in Section 1.2.2, Vistra has proposed two configurations for the BESS facility, one where the batteries would be contained in three buildings (Proposed Project), as shown in **Figure 1-1**, and another configuration where the batteries would be contained in 174 separate enclosures (Enclosure Alternative), as shown in **Figure 1-2**.

Figure 1-1: Project overview and boundaries (Proposed Project)

Figure 1-2: Project overview and boundaries (Enclosure Alternative)

All facilities related to the proposed BESS would be located on the 24-acre subsection of the Project Site (BESS Site), as shown in **Figure 1-1** and **Figure 1-2**. The BESS Site is located along the western side of the Project Parcel and would include all energy storage systems and any supporting facilities (access roads, power conversion systems, substations, etc.) for the proposed BESS facility.

The proposed BESS would have a total power and energy storage capacity of 600MW and 2,400MWh, respectively. The BESS would provide power to utility customers by interconnecting to the existing PG&E switchyard located east of the Project Site. The BESS would operate year-round to store and discharge electricity to support demand on the power grid, improve the reliability of California's increasingly low-carbon grid, and facilitate the efficient use of renewable energy resources.

1.2.2 Proposed Layouts

Vistra has prepared two principal layouts for the proposed BESS, as briefly described below. Both layouts would allow the BESS facility to be located entirely within the 24-acre BESS Site. Please refer to the Draft Environmental Impact Report (DEIR) prepared by the City of Morro Bay for further details concerning the proposed project.[1]

The following **Figure 1-3** depicts several components of a typical BESS using lithium-ion batteries (LiB), including battery cells, modules, and racks. For the Proposed Project, racks will be clustered into “blocks.” For the Enclosure Alternative, racks will be clustered into “battery strings” that will be placed in an enclosure.

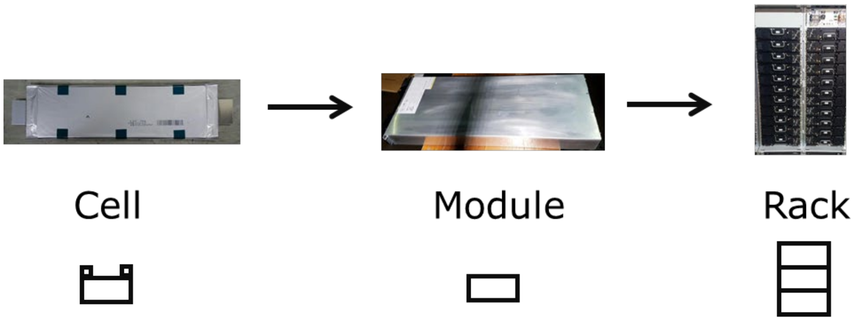

Figure 1-3: Example of BESS components

The **Proposed Project** involves locating the batteries in three buildings, as shown in Figure 1-1. Each building would contain approximately 2,400 battery racks, or 60,000 battery modules (on average 25 modules per rack), and would be surrounded by approximately 60 Power Conversion Systems (PCSs). The three two-story Battery Storage Buildings would each cover a 91,000 sqft area (350 ft x 260 ft), and be 30 feet tall. **Figure 1-4** shows an example of a battery rack with modules inside the rack.

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[1] City of Morro Bay, Draft Environmental Impact Report for the 600-MW Morro Bay Battery Energy Storage Project (SCH 2022060083). https://www.morrobayca.gov/842/Current-Planning-Projects.

Figure 1-4: Example of battery rack with modules

The total power capacity and energy storage capacity contained in each building is expected to be 200 MW and 800 MWh respectively, one third of the total BESS capacity. Each rack would be approximately 9 to 24 feet tall, pending final design refinements. The racks will then be grouped into blocks, each with their own access, fire protection, and safety systems.

The **Enclosure Alternative** would be comprised of 174 enclosures (containers), each housing 46 rack-mounted battery strings. Each string would contain 16 battery modules for a total of 736 modules in each enclosure. Each enclosure would have approximate dimensions of 55 ft x 14 ft x 15 ft, and would be arranged in a single story (i.e., enclosures will not be stacked). PCSs would be located adjacent to each enclosure on a shared concrete pad. The enclosures would all be spaced 10 ft apart and organized into "groups" of up to eight (8) enclosures, with each group spaced a minimum of 25 ft apart. Each enclosure would have its own fire protection and thermal management system.

Regardless of layout, the proposed BESS facility will be located on an elevated portion of the project site that previously contained the tank farm associated with the decommissioned Morro Bay Power Plant. Siting the facility outside the Federal Emergency Management Agency 500-year flood mark aligns with suggested best siting practices for BESS facilities.[2]

As explained in the DEIR, although the site is located near the ocean, flooding from a tsunami is unlikely to reach the batteries. There has been no recorded flooding of the project site due to tsunamis in the past, and the existing sand spit, Morro Rock, and the narrow harbor entrance

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[2] Lawrence Berkeley National Laboratory. (2022) *Best Practices and Considerations for Siting Battery Energy Storage Systems*.

would prevent or limit inundation due to tsunamis. In addition, the existing 33-foot earthen berms surrounding much of the site, including to the west of the tank farm area, will further protect the batteries from tsunamis.

The DEIR explains that while the project site is in a seismically active area of California, it does not overlie any known fault, and the nearest mapped fault zone is 9.3 miles to the south. The absence of any known faults in close proximity to the project substantially reduces the risk of ground surface ruptures. Furthermore, the BESS would be required to comply with California Building Code requirements applicable to BESS that require analysis and calculations to ensure seismic safety.[3]

The DEIR prepared by the City of Morro Bay contains additional discussion of potential environmental impacts associated with the BESS facility.[4]

1.2.3 Proposed Battery Technology

When developing a BESS, the choice of battery technology depends on various factors, including cost, energy density, safety, and cycle life. The most common LiBs for a BESS are:

- Lithium Nickel Manganese Cobalt Oxide (NMC - $LiNiMnCoO_2$)
- Lithium Iron Phosphate (LFP - $LiFePO_4$)

Both battery technologies (NMC and LFP) are used widely and well understood. For batteries, the higher the thermal runaway temperature, the less likely thermal runaway is to occur. LFP has a relatively high thermal runaway temperature of 518°F (270°C).[5] In contrast, NMC batteries, known for their high energy density, have a lower thermal runaway temperature of 410°F (210°C).[6] Scientific experiments have demonstrated that the maximum total internal heat generated (or simply, the heat or energy release) by fully charged LFP batteries is a third of that generated by NMC batteries[7], which is attributable to their lower energy density. LFP batteries exhibit low flammability due to their stable chemistry. Meanwhile, NMC batteries display higher flammability. LFP batteries are recognized for their safety benefits and longer life cycles.

This report assumes the batteries used at this site would be LiB, which is consistent with Vistra's initial project application and the broader industry as most BESS facilities in operation today use LiBs. As discussed in Section 3, to evaluate offsite risks from a fire event at the facility, this OCA uses the highest reliable emissions factors identified in the literature concerning emissions from battery fires. We note that most of that literature evaluates fires from NMC batteries, which tend

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[3] Division of the State Architect. (2023) *IR N-4: Modular Battery Energy Storage Systems: 2022 CBC and CFC*.

[4] City of Morro Bay, Draft Environmental Impact Report for the 600-MW Morro Bay Battery Energy Storage Project (SCH 2022060083). https://www.morrobayca.gov/842/Current-Planning-Projects.

[5] A. Zhukov (2023). Cell-to-pack LFP Lithium Batteries Outperform NMC. Available at: https://www.onecharge.biz/blog/cell-to-pack-lfp-lithium-batteries-outperform-nmc/ accessed on March 14, 2024

[6] A. Zhukov (2023). Cell-to-pack LFP Lithium Batteries Outperform NMC. Available at: https://www.onecharge.biz/blog/cell-to-pack-lfp-lithium-batteries-outperform-nmc/ accessed on March 14, 2024

[7] Liu et al. (2016). Heat release during thermally-induced failure of a lithium ion battery: Impact of cathode composition. Fire Safety Journal, vol. 85, pp. 10-22, 2016. https://doi.org/10.1016/j.firesaf.2016.08.001

to burn at higher temperatures and experience higher rates of consumption.[8,9] The emissions factors presented in this report are therefore conservative estimates that over-predict the emissions likely to occur at BESS facilities, particularly those that employ LFP batteries.

1.3 Lithium-ion Batteries

A LiB is a rechargeable battery which uses the reversible reduction of lithium ions to store energy. The main parts of a LiB are an anode, cathode, separator, electrolyte, and two (positive and negative) current collectors. The materials used in both the anode and cathode must be able to store and release lithium ions. The separator is permeable to positively charged lithium ions (Li+) carried in the electrolyte from the anode to the cathode and vice versa; however, it blocks the transport of electrons inside the battery, thereby preventing short-circuiting.[10] The anode of a conventional LiB cell is typically graphite made from carbon. The cathode is typically a metal oxide such as Lithium Cobalt Oxide ($LiCoO_2$ or LCO), Lithium-Nickel-Manganese-Cobalt-Oxide ($LiNiMnCoO_2$ or NMC), Lithium Manganese Oxide ($LiMn_2O_4$ or LMO), Lithium Titanate (LTO), Lithium Nickel Cobalt Manganese Oxide (NCM) or Lithium Iron Phosphate (LFP).[11] The electrolyte is typically a lithium salt such as $LiPF_6$ (Lithium hexafluorophosphate) or $LiBF_4$ (Lithium tetrafluoroborate) dissolved in an organic solvent.[12]

When a LiB is charged, Li+ ions initially stored at the cathode dissolve, due to the current passed to the battery by the charger. The ions are released into the electrolyte and flow to the anode where they are accommodated within the anode material. This process creates a potential difference between the two electrodes, and that difference is maintained by the separator, which blocks the flow of ions and associated electrons inside the battery. When a load is connected to the battery, it draws the electric current, resulting in a battery discharge as the electrons to which the Li+ ions were tied at the anode are released. Simultaneously, inside the battery, the anode releases Li+ ions through the electrolyte and separator to the cathode.[13] This is shown schematically in **Figure 1-5**.

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[8] Chen Y. et al. (2021) A review of lithium-ion battery safety concerns: The issues, strategies, and testing standards. Journal of Energy Chemistry 59 https://doi.org/10.1016/j.jechem.2020.10.017

[9] Rorder P. et al. (2013) Impact of delithiated Li0FePO4 on the decomposition of LiPF6-based electrolyte studied by accelerating rate calorimetry. Journal of Power Sources, 236 http://dx.doi.org/10.1016/j.jpowsour.2013.02.044

[10] Da D. (2015) Li-ion batteries: basics, progress, and challenges. Energy Science and Engineering, 3 https://doi.org/10.1002/ese3.95

[11] Mekonnen Y. et al. (2016) A Review of Cathode and Anode Materials for Lithium-Ion Batteries. IEEE Xplore. DOI: 10.1109/SECON.2016.7506639

[12] Li Q. et al. (2016) Progress in electrolytes for rechargeable Li-based batteries and beyond. Green Energy & Environment, 1 http://dx.doi.org/10.1016/j.gee.2016.04.006

[13] Lee H. et al. (2014) A review of recent developments in membrane separators for rechargeable lithium-ion batteries. Energy & Environmental Science, 12. DOI: 10.1039/c4ee01432d

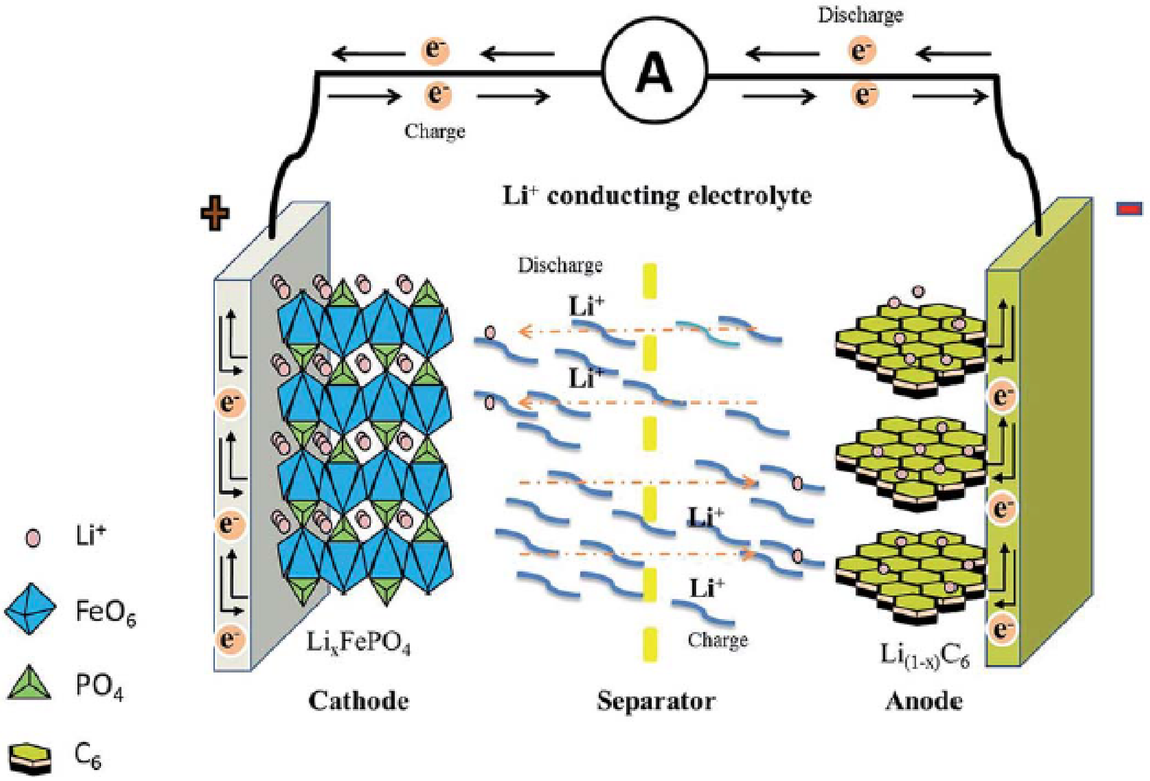

Figure 1-5: Scheme of Li ion transport in LiB[14]

LiBs are the preferred battery technology for many commercial and industrial uses because they have high energy density, meaning they can store more energy in a smaller unit. This high energy density is a function of lithium's small atomic weight and radius, which allows for more ions, and ultimately more electricity, to be generated per unit of mass. LiBs' high energy density make them a preferred choice in applications which require compact design and mobility such as consumer electronics and electric vehicles.[15] LiBs are relatively low maintenance compared to other technologies because they do not require frequent cycling to maintain battery life. LiBs also tend to have lower self-discharge rates and usually do not contain toxic materials commonly found in other batteries, such as lead or cadmium.[16]

In general, LiBs are stable under normal operations and conditions. However, in certain cases damaged or compromised batteries can lead to failure, which could result in fires. One of the main risks associated with LiBs, as well as other types of batteries, is thermal runaway. Thermal

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[14] Lee H. et al. (2014) A review of recent developments in membrane separators for rechargeable lithium-ion batteries. *Energy & Environmental Science*, 12. DOI: 10.1039/c4ee01432d

[15] Rangarajan et al. (2022) Lithium-Ion Batteries—The Crux of Electric Vehicles with Opportunities and Challenges. Clean Technol. 4, 908-930; https://doi.org/10.3390/cleantechnol4040056

[16] University of Washington. Clean Energy Institute. Lithium-Ion Battery: https://www.cei.washington.edu/research/energy-storage/lithium-ion-battery/#:~:text=Li%2Dion%20batteries%20are%20comparatively,'remember'%20a%20lower%20capacity accessed on March 8, 2024.

runaway occurs when a battery cell, or area within the cell, enters a self-propagating heating state due to internal failure such as internal defects, or due to external mechanical, thermal, or electrical stress.[17] In the unlikely event that a series of safeguards fails, this thermal runaway can result in heat generation exceeding the potential for heat dissipation, potentially leading to thermal breakdown and volatilization of materials in the cell.[18,19,20] Susceptibility of a LiB to thermal runaway depends on the chemical and physical properties of the battery materials and components, the potential for internal defects in battery components, and overall battery design, which incorporates various safety features. The chemical and thermal stability of the cathode material largely determines the stability of any specific type of LiB. The higher energy density of LiBs relative to other battery types also means that there is more stored energy available to propagate thermal runaway and heat, which could potentially ignite the flammable liquid electrolyte.[21,22]

As noted in Section 1.2, LFP is a type of lithium-ion battery with a cathode material that has higher thermal and chemical stability than other LiBs. The high covalent feature of the P–O bonds in the tetrahedral (PO3-4) units makes the crystalline structure of the cathode very stable and slows the oxygen release from the cathode during the charge cycle or malfunction.[23] This minimizes the risks of thermal runaways and self-propagation, reducing the risks of fire and explosion. Thermal runaway of an LFP battery is intrinsically difficult to trigger under normal operations.[24] The delithiated $LiFePO_4$ also inhibits the exothermal decomposition of $LiPF_6$-based electrolyte, which may reduce the risks of fire and explosion.[25] In addition to being considered one of the safest battery types, LFPs have a long cycle and calendar life and they can operate over a wider temperature range than other LiBs without damage to the battery or power degradation. Having lower energy density relative to NMC, LFP may not be the battery of choice for compact and wearable devices; however, its proven safety and reliability make it suitable for large commercial and industrial operations, including power station energy storage systems.[26]

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17 IOP Publishing: https://iopscience.iop.org/article/10.1149/1945-7111/aba8b9/meta#back-to-top-target accessed on December 16, 2022.

[18] Mitsubishi Electric. What is thermal runaway? https://www.mitsubishicritical.com/resources/blog/thermal-runaway/ accessed on February 3, 2023.

[19] Saur Energy International. Why do Lithium-Ion Batteries Catch Fire? How to Avoid the Mishap? https://www.saurenergy.com/solar-energy-blog/why-do-lithium-ion-batteries-catch-fire-how-to-avoid-the-mishap#:~:text=Apart%20from%20that%2C%20in%20intense,gases%20causes%20fires%20and%20explosions accessed on December 23, 2022.

[20] U.S. Department of Energy: Office of Scientific and Technical Information: https://www.osti.gov/pages/servlets/purl/1235360#:~:text=While%20other%20materials%20are%20being,ethyl%20methyl%20carbonate%20(EMC) accessed on December 23, 2022.

[21] Lamb J. et al. (2021) Investigating the Role of Energy Density in Thermal Runaway of Lithium-Ion Batteries with Accelerating Rate Calorimetry. J. Electrochem. Soc. 168 DOI 10.1149/1945-7111/ac0699

[22] Willstrand O. et al (2023) Impact of different Li-ion cell test conditions on thermal runaway characteristics and gas release measurements. J. Energy Storage. 68 https://doi.org/10.1016/j.est.2023.107785

[23] Ren J. et al. (2023) Typical cathode materials for lithium-ion and sodium-ion batteries: From structural design to performance optimization. Carbon neutralization, 2 https://doi.org/10.1002/cnl2.62

[24] PowerTech. Safety of Lithium-Ion batteries https://www.powertechsystems.eu/home/tech-corner/safety-of-lithium-ion-batteries/ accessed on February 5, 2024

[25] Rorder P. et al. (2013) Impact of delithiated Li0FePO4 on the decomposition of LiPF6-based electrolyte studied by accelerating rate calorimetry. Journal of Power Sources, 236 http://dx.doi.org/10.1016/j.jpowsour.2013.02.044

[26] Rey S.O. et al. (2023) Powering the Future: A Comprehensive Review of Battery Energy Storage Systems. Energies, 16 https://doi.org/10.3390/en16176344

1.4 Battery Energy Storage Systems

A principal benefit of BESS facilities is that they make renewable energy more reliable and thus more viable. Supplies of renewable energy resources such as wind and solar can fluctuate throughout the day, often providing the greatest amounts of electricity in the middle of the day. BESS facilities improve grid reliability by storing excess renewable energy during times when the supply is greater, and dispatching that energy during times of peak demand. Stated differently, energy storage facilities allow for efficient use of renewable energy when the sun goes down or winds stop blowing. This makes batteries a key tool to combat climate change, because they enable a more flexible energy supply that maximizes the use of renewable energy.

The California Public Utility Commission (CPUC) recently adopted a portfolio for utility procurement that requires the statewide addition by 2035 of 15.7 GW of four-hour duration LiBs, in addition to 2.8 GW of eight-hour duration LiBs and .5 GW of long-duration energy storage.[27] A 2023 report commissioned by the CPUC noted the need for more storage to pair with California's planned deployment of renewable energy in the coming decades.[28] That report explained that energy storage provides a wide range of services in a renewable-focused grid, such as increased reliability and more efficient delivery of energy to users. Energy storage sites near end users are especially efficient as there is a lower loss of energy compared to transmission over long distances.

1.4.1 Current Number of BESS facilities in the United States

Battery storage capacity in the United States has been growing rapidly. The United States Energy Information Agency (EIA) states: "U.S. battery storage capacity has been growing since 2021 and could increase by 89% by the end of 2024 if developers bring all of the energy storage systems they have planned on line by their intended commercial operation dates."[29] The EIA states that developers plan to expand battery capacity in the United States to more than 30 gigawatts (GW) by the end of 2024, as shown in **Figure 1-6**. As shown in **Table 1-1,** as of 2022, most of the installed capacity was LiB. **Figure 1-7** shows the number of projects installed as of 2022.

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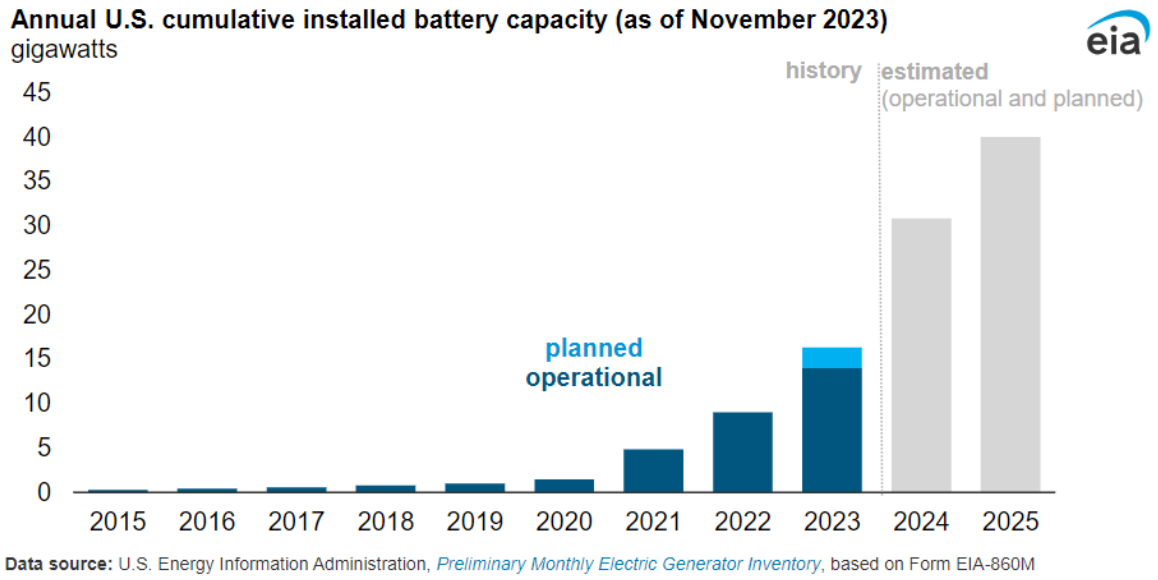
[27] CPUC (2024) Decision 24-02-047: Decision Adopting 2023 Preferred System Plan And Related Matters, and Addressing Two Petitions For Modification. https://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M525/K918/525918033.PDF

[28] California Public Utilities Commission. Energy Storage Procurement Study. 2023-05-31_lumen_energy-storage-procurement-study-report-attf.pdf (ca.gov) accessed on January 29, 2024.

[29] EIA. U.S. Battery Storage Capacity Expected to Nearly Double in 2024. https://www.eia.gov/todayinenergy/detail.php?id=61202, accessed on March 4, 2024.



Annual U.S. cumulative installed battery capacity (as of November 2023)

Data source: U.S. Energy Information Administration, *Preliminary Monthly Electric Generator Inventory*, based on Form EIA-860M

Figure 1-6: Annual US Cumulative Installed and Planned Battery Capacity[30]

Table 1-1: Results from EIA-860 for 2022 Energy Storage Installations in the United States

Energy Storage Technology	Number of Energy Storage Projects	Maximum Discharge Rate (MW)	Nameplate Energy Capacity (MWh)
Electro-chemical battery and chemical storage	449	8796.4	23676.2
Lithium-ion battery (LiB)	429	8711.7	23581.7
Lead-acid battery (PBB)	5[31]	--	--
Flow battery (FLB)	3	17.0	33.0
Nickel-based battery (NIB)	4	47.5	26.3
Sodium-based battery (NAB)	2	4.0	4.0
Other	6	16.2	31.2

Notes:

- Data from the EIA-860. Available from https://www.eia.gov/electricity/data/eia860/ (accessed February 6, 2024).
- File used: "3_4_Energy_Storage_Y2022.xlsx", from (https://www.eia.gov/electricity/data/eia860/xls/eia8602022.zip)
- All "Operable" Energy Storage projects, with technology listed as "Batteries" and Maximum Discharge Rates > 1MW. Includes all Status Codes, including those "Out of Service".

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[30] EIA. U.S. Battery Storage Capacity Expected to Nearly Double in 2024. https://www.eia.gov/todayinenergy/detail.php?id=61202, accessed on March 4, 2024.

[31] There were 5 projects that used PPB, but they were all below the threshold of 1 MW, which are those reported in the table.

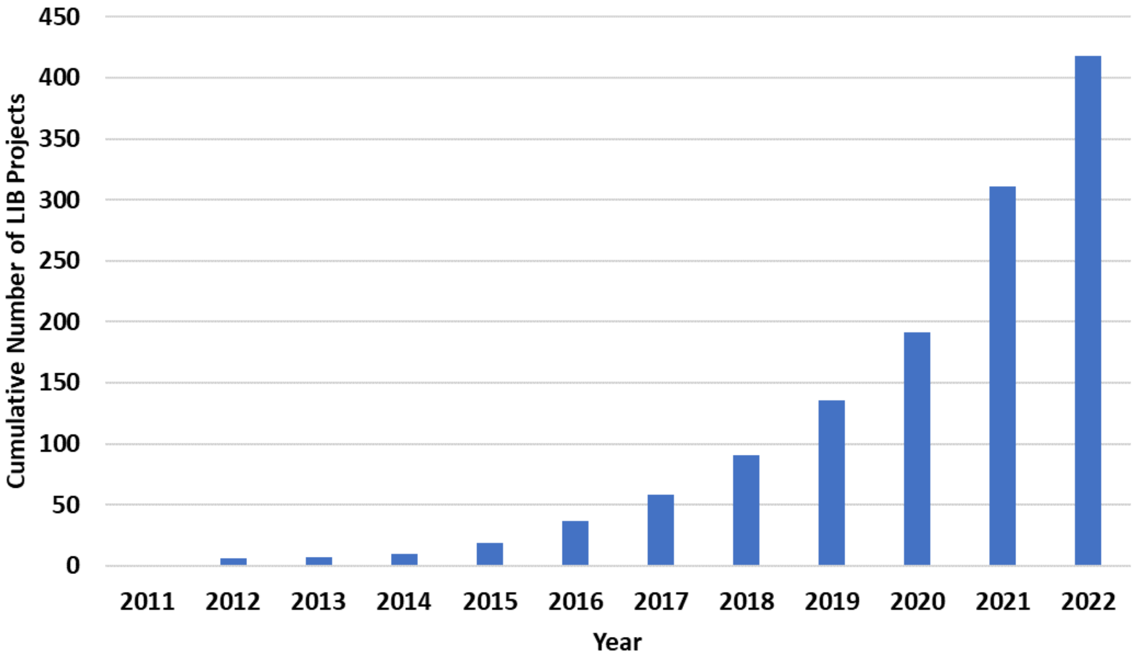

Figure 1-7: LiB BESS Growth in United States (2011-2022)

1.5 Potential BESS Hazards – Thermal Events and Explosions

As further explained in Section 2, significant strides have been made in recent years to improve the safety performance of BESS facilities. In April 2023, the Pacific Northwest National Laboratory calculated that less than three percent (3%) of large, utility-scale BESS facilities had experienced a fire incident.[32]

Like many other industrial and energy infrastructure uses, BESS facilities involve potential safety risks. This section discusses potential hazards associated with BESS facilities.

1.5.1 Hazard Description

Hazards related to BESS facilities can be broadly classified as electrical (shock, arc flash), chemical (toxic emissions), and thermal (fires, explosions). The main hazard concern with BESS facilities using LiB is the risk of thermal runaway, which can lead to the venting of flammable and/or toxic gases and the possibility of fire or explosion. These hazards are the main drivers for the development of codes and standards relating to BESS facilities.[33] BESS facilities are not expected to pose a significant risk of water, soil, or habitat impacts.[34]

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[32] Pacific Northwest National Laboratory. (October 2023) Energy Storage in Local Zoning Ordinances 4 https://www.pnnl.gov/main/publications/external/technical_reports/PNNL-34462.pdf

[33] EPRI. (2023) The Evolution of Battery Energy Storage Safety Codes and Standards. 2023 White Paper. https://www.epri.com/research/products/000000003002028521

[34] EPRI. (2020) *Environmental Aspects of Utility-Scale Energy Storage Systems* 23-26

Thermal runaway events can occur during battery handling, installation and use, as well as from defects in battery design and manufacturing. The most common types of battery stress that can lead to thermal runaway (discussed in Section 1.3) include:

- Thermal: heat stress due to internal or external overheating coupled with high ambient temperatures, poor ventilation, or poor design;
- Mechanical: mechanical damage to the battery container such as deformation or puncture; and
- Electronic: battery is charged rapidly, overcharged, or over discharged resulting in a short circuit.

If thermal runaway continues to a point where cell temperatures meet or exceed the ignition point of the cell's organic solvents, a fire or explosion hazard can be created. Further, fires or explosions can occur even in the absence of an internal ignition source because increasing pressure in the cell can lead to a breach of the separator and the venting of gases from the cell into an external environment, which can then ignite. The amount of heat generated in this process could also trigger thermal runaway in adjacent cells.[35] Fires are more likely to happen in uncontrolled environments such as in private residences which have no specific measures to mitigate and monitor heat rise.

LiB fires and explosions can be accompanied by the release of gaseous and particulate contaminants, some of which may be toxic. Some of the contaminant species commonly associated with battery fires include gases such as hydrofluoric acid (HF), hydrochloric acid (HCl), hydrogen cyanide (HCN), carbon monoxide (CO), benzene, and various carbonaceous and metal-bound particulate matter.[36,37] A more comprehensive review of the airborne contaminants that could be released from LiB fires is provided in Section 3.

1.5.2 Review of Historic BESS Thermal Events

Fires can be defined as "a process involving rapid oxidation at elevated temperatures accompanied by the evolution of heated gaseous products of combustion, and the emission of visible and invisible radiation."[38] Explosions are chain reactions that occur where "gas and heat are accumulated" [39] and then ignite and overcome the pressure resistance of a container. The term incident could involve "smoke, fire, or extreme heat."[40] Several sources were used to identify past BESS fires and explosions.[41]

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[35] Feng, X., et al. (2015) Thermal runaway propagation model for designing a safer battery pack with 25 Ah $LiNi_xCO_yMn_zO_2$ large format lithium ion battery. Applied Energy 154 p.74-91.

[36] DNV GL. McMicken Battery Energy Storage System Event Technical Analysis and Recommendations. https://www.aps.com/-/media/APS/APSCOM-PDFs/About/Our-Company/Newsroom/McMickenFinalTechnicalReport.ashx?la=en&hash=50335FB5098D9858BFD276C40FA54FCE accessed on February 2, 2023.

[37] Zhang, Y. et al., (2019) "Quantitative identification of emissions from abused prismatic Ni-rich lithium-ion batteries", eTransportation 2.

[38] Wang, Q., Sun, J., and Chu, G. (2005) Lithium ion battery fire and explosion. *Fire Safety Science* 8, 375-382.

[39] Wang, Q., Sun, J., and Chu, G. (2005) Lithium ion battery fire and explosion. *Fire Safety Science* 8, 375-382.

[40] Federal Aviation Administration. Lithium Battery Incidents. https://www.faa.gov/hazmat/resources/lithium_batteries/incidents, accessed on February 6, 2024.

[41] According to the National Fire Protection Association (NFPA) Glossary of Terms, it defines an explosion as "The bursting or rupture of an enclosure or container due to the development of internal pressure from a

As part of this report, Ramboll performed an independent review of publicly available databases and other literature concerning historic BESS thermal events. The results of that review are summarized in Appendix A. As of this writing, we have not identified significant offsite health impacts or injuries from any BESS thermal event. Furthermore, while Appendix A shows an increase in thermal events over time, **Figure 1-8** shows that the number of thermal events per MW of installed BESS capacity has been decreasing over time, demonstrating the improved safety performance for these installations.

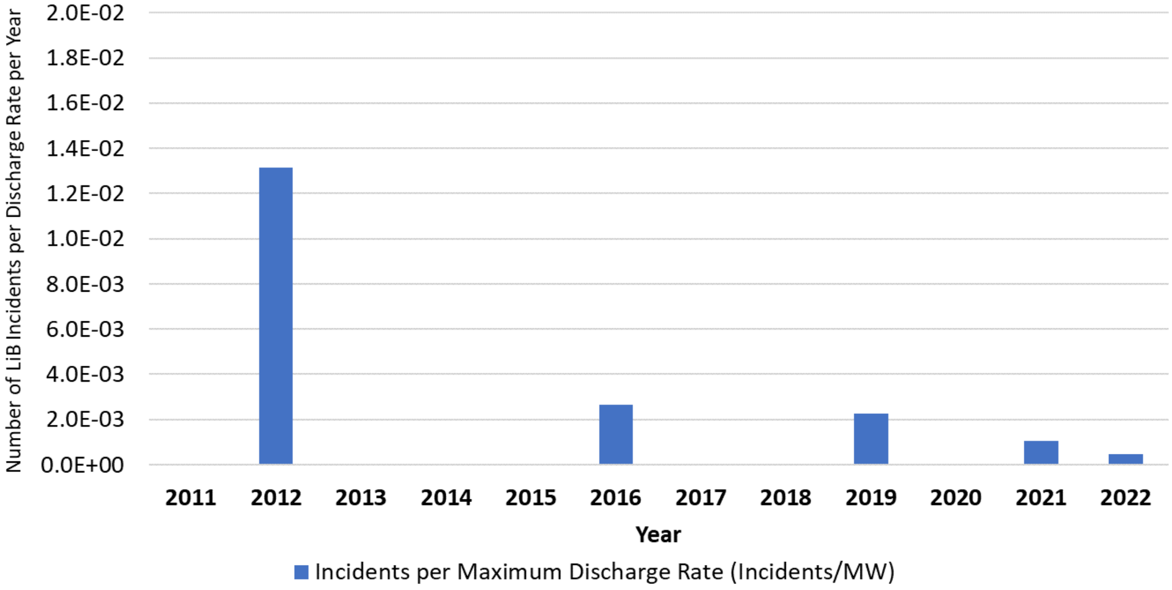

Figure 1-8: Number of incidents per discharge rate

1.5.3 Assessment of Airborne Releases from Fires

Air toxics, also known as hazardous air pollutants (HAPs), are defined by the federal Clean Air Act (CAA) as contaminants that are "known or suspected to cause cancer or other serious health effects, such as reproductive effects or birth defects, or adverse environmental effects."[42] HAPs are emitted into ambient air from a range of industrial facilities and vehicles. Under section 112(k) of the 1990 amendments to the CAA, the US EPA originally identified 189 pollutants as HAPs by statute. The list has been amended several times and it currently includes 188 pollutants (although it does not include all chemicals that can cause acute effects).[43] For example, HAPs include certain volatile organic chemicals (e.g. benzene and toluene, which are present in gasoline or chlorinated organic liquids used as solvents or in dry cleaning); inorganic gases (e.g.

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deflagration." and a fire as "A rapid oxidation process, which is a chemical reaction resulting in the evolution of light and heat in varying intensities." NFPA. Glossary of Terms. https://www.nfpa.org/~/media/Files/Codes%20and%20standards/Glossary%20of%20terms/glossary_of_terms_2021.ashx . Accessed on January 30, 2023.

[42] USEPA. What are Hazardous Air Pollutants? Available at: https://www.epa.gov/haps/what-are-hazardous-air-pollutants

[43] USEPA. Initial List of Hazardous Air Pollutants with Modifications. Available at: https://www.epa.gov/haps/initial-list-hazardous-air-pollutants-modifications#mods

hydrogen chloride and chlorine, which have wide application in industry including as household cleaning products and disinfectants); and metals (e.g. chromium, which is released in ferrochrome, certain chemical and pigment manufacturing, and found in vehicle exhaust due to the wear of automobile breaks and catalytic converters).[44]

Exposure to HAPs can lead to acute and/or chronic health effects. Acute health effects represent adverse effects associated with a brief exposure[45] to high concentrations of a pollutant. The symptoms manifest immediately or soon after the exposure and typically subside soon after the cause is removed.[46] Examples of acute health effects include respiratory irritation, cough, and dizziness. Chronic health effects are the result of long-term exposure to a pollutant. The adverse health effects manifest only after continued exposure and usually do not subside when the exposure stops. Examples of chronic health effects include asthma and cancer.[47]

Guidance documents and reference values have been developed to evaluate the impacts of potential exposure to HAPs.[48] The two most broadly accepted guidelines on acute exposure are:

- **Acute Exposure Guideline Levels** (AEGLs) originally developed by the National Advisory Committee for Acute Exposure Guideline Levels for Hazardous Substances.[49]
- **Emergency Response Planning Guidelines** (ERPGs) developed by the Emergency Response Planning committee of the American Industrial Hygiene Association.[50]

AEGLs describe the "human health effects from once-in-a-lifetime, or rare, exposure to airborne chemicals." AEGLs are reported as a concentration (in ppm or mg/m^3) of a given airborne contaminant at which the described health effects would occur if a human is exposed to that concentration for a certain duration (e.g., 10 minutes, 60 minutes, 8 hours). AEGL values (concentration levels) for different exposure periods differ because the same health effect could be a result of a brief exposure to a very high concentration of the contaminant, or a prolonged exposure to a lower concentration. For a given exposure duration (e.g., 1 hour) AEGLs may have three values, with each describing different health effects from mild (or transient), moderate, to serious (irreversible) as shown in Table 1-2. There are defined AEGLs for many chemicals, including those that may cause adverse health effects but are not classified as HAPs under the CAA.

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[44] USEPA. Health Effects Notebook for Hazardous Air Pollutants. https://www.epa.gov/haps/health-effects-notebook-hazardous-air-pollutants

[45] Acute exposure typically refers to the exposure duration at the order of minutes and hours.

[46] University of Illinois Urbana-Champaign. Health Effects of Chemical Exposure. https://drs.illinois.edu/Page/SafetyLibrary/HealthEffectsOfChemicalExposure

[47] ibid

[48] Acute Exposure Guideline Levels for Airborne Chemicals. https://www.epa.gov/aegl

[49] History of Acute Exposure Guideline Levels (AEGLs). https://www.epa.gov/aegl/history-acute-exposure-guideline-levels-aegls

[50] ERPGs (Emergency Response Planning Guidelines™). https://www.aiha.org/get-involved/aiha-guideline-foundation/erpgs

Table 1-2: Definitions of Acute Exposure Guideline Levels (AEGLs)

	Definitions[51]
AEGL-1	AEGL-1 is the airborne concentration (expressed as parts per million (ppm) or mg/m^3) of a substance above which it is predicted that the general population, including susceptible individuals, could experience notable discomfort, irritation, or certain asymptomatic nonsensory effects. However, the effects are not disabling and are transient and reversible upon cessation of exposure.
AEGL-2	AEGL-2 is the airborne concentration (expressed as ppm or mg/m^3) of a substance above which it is predicted that the general population, including susceptible individuals, could experience irreversible or other serious, long-lasting adverse health effects or an impaired ability to escape.
AEGL-3	AEGL-3 is the airborne concentration, expressed as ppm or milligrams per cubic meter (mg/m^3), of a substance above which it is predicted that the general population, including susceptible individuals, could experience life-threatening health effects or death.

ERPGs identify the concentration levels at which people will begin to experience health effects if exposed to a hazardous chemical for 1 hour.[52,53] The three EPRG levels (corresponding to mild, moderate, and serious effects) are defined as shown in **Table 1-3**.

Table 1-3: Definitions of Emergency Response Planning Guidelines (ERPGs)

	Definitions[54]
ERPG-1	ERPG-1 is the maximum airborne concentration below which nearly all individuals could be exposed for up to 1 hour without experiencing more than mild, transient adverse health effects or without perceiving a clearly defined objectionable odor.
ERPG-2	ERPG-2 is the maximum airborne concentration below which nearly all individuals could be exposed for up to 1 hour without experiencing or developing irreversible or other serious health effects or symptoms which could impair an individual's ability to take protective action.
ERPG-3	ERPG-3 is the maximum airborne concentration below which nearly all individuals could be exposed for up to 1 hour without experiencing or developing life-threatening health effects.

1.6 Introduction to Offsite Consequence Analysis

In this section, we discuss the purpose of an offsite consequence analysis (OCA) and some of the local information needed to conduct an OCA.

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[51] Acute Exposure Guideline Levels (AEGLs). https://response.restoration.noaa.gov/oil-and-chemical-spills/chemical-spills/resources/acute-exposure-guideline-levels-aegls.html accessed on February 3, 2023.

[52] ERPGs (Emergency Response Planning Guidelines™). https://www.aiha.org/get-involved/aiha-guideline-foundation/erpgs

[53] Emergency Response Planning Guidelines (ERPGs). https://response.restoration.noaa.gov/oil-and-chemical-spills/chemical-spills/resources/emergency-response-planning-guidelines-erpgs.html

[54] Emergency Response Planning Guidelines (ERPGs) https://response.restoration.noaa.gov/oil-and-chemical-spills/chemical-spills/resources/emergency-response-planning-guidelines-erpgs.html accessed on February 3, 2023.

1.6.1 Purpose

The purpose of an OCA is to identify the hazards and risks associated with releases of hazardous chemicals, including unplanned or accidental releases associated with handling and storing of hazardous chemicals or otherwise using materials that may release hazardous chemicals. In the case of BESS projects, an OCA can be used to identify the potential impacts from the release of airborne toxics during a fire. This report relies on general guidelines from the US EPA ("Risk Management Program Guidance for Offsite Consequence Analysis")[55], the California EPA ("California Accidental Release Prevention")[56], and San Luis Obispo County ("A Guide for Assessing the Air Quality Impacts for Projects Subject to CEQA Review")[57]. However, we note that this project is not required to prepare an OCA under 40 CFR Part 68 because it is not expected to have any regulated substances at or above threshold levels (40 CFR Part 68.130).[58] Instead, this OCA was conducted to evaluate the reasonable worst-case release scenario in the event of a maximum credible fire event.

The US EPA guidance for OCAs indicates the scenario modeled should represent "the release of the largest quantity of a regulated substance from a vessel or process line failure, and the release that results in the greatest distance to the endpoint for the regulated toxic or flammable substance."[59] The US EPA guidance document also requires that the model reflect the worst-case atmospheric stability at class F (stable atmosphere), wind speeds of 1.5 meters per second (3.4 miles per hour), and ambient temperature of 25°C (77°F).[60] These parameters ensure a conservative assessment of potential health and safety risks. Additional required parameters for modeling scenarios are included in 40 CFR 68.22[61] and Exhibit 1 in the US EPA guidance document.[62]

The US EPA guidance document says that it is possible to "…use either publicly available or proprietary air dispersion models…" for an offsite consequence analysis.[63] The EPA has developed a software based on the RMP Offsite Consequence Analysis Guidance[64] where users can select a compound of interest and enter worst-case source parameters and meteorological assumptions to estimate the distance at which AEGLs (or ERPGs) concentrations are reached. These distances

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[55] USEPA. Risk management program guidance for offsite consequence analysis. https://www.epa.gov/sites/default/files/2013-11/documents/oca-chps.pdf accessed on January 20, 2023.

[56] CalEPA. California Accidental Release Prevention. https://calepa.ca.gov/cupa/lawsregs/california-accidental-release-prevention/ accessed on January 20, 2023.

[57] County of San Luis Obispo County. A Guide for Assessing the Air Quality Impacts for Projects Subject to CEQA Review. https://storage.googleapis.com/slocleanair-org/images/cms/upload/files/CEQA_Handbook_2012_v2%20%28Updated%20MemoTable1-1_July2021%29_LinkedwithMemo.pdf accessed on February 1, 2023

[58] National Archives. 68.130 List of substances. https://www.ecfr.gov/current/title-40/chapter-I/subchapter-C/part-68/subpart-F/section-68.130 accessed on January 20, 2023.

[59] USEPA. Risk management program guidance for offsite consequence analysis. https://www.epa.gov/sites/default/files/2013-11/documents/oca-chps.pdf accessed on January 20, 2023.

[60] U.S. Government Publishing Office. 40 CFR Part 68.22 Offsite consequence analysis parameters. https://www.govinfo.gov/content/pkg/CFR-2000-title40-vol10/pdf/CFR-2000-title40-vol10-sec68-22.pdf

[61] GovInfo. 40 CFR 68.22 – Offsite consequence analysis parameters. https://www.govinfo.gov/content/pkg/CFR-2000-title40-vol10/pdf/CFR-2000-title40-vol10-sec68-22.pdf accessed on January 20, 2023.

[62] USEPA. Risk management program guidance for offsite consequence analysis. https://www.epa.gov/sites/default/files/2013-11/documents/oca-chps.pdf accessed on January 20, 2023.

[63] USEPA. Risk management program guidance for offsite consequence analysis. https://www.epa.gov/sites/default/files/2013-11/documents/oca-chps.pdf accessed on January 20, 2023.

[64] EPA. RMP*Comp. https://www.epa.gov/rmp/rmpcomp accessed on January 20, 2023.

represent the toxic endpoints and are used to determine the distances or areas where specific exposure guidance levels are exceeded.[65] A commonly used model for OCAs is the Areal Locations of Hazardous Atmospheres (ALOHA) model developed by the National Oceanic and Atmospheric Administration (NOAA) and the US EPA.[66]

It is important to note that an OCA does not consider the probability of a release or the probability of worst-case conditions occurring. Rather, it assumes that a release occurs under such conditions and evaluates the resulting reasonably anticipated consequences.

1.6.2 OCA Considerations

Because an OCA is intended to evaluate the hazards and risks associated with a specific facility in a specific location, it is necessary to consider several site-specific factors. The sections below briefly discuss two key elements of this OCA: local surroundings and local meteorological conditions.

1.6.2.1 Local Surroundings

The BESS Site is surrounded by open space and recreation areas to the north and west (Morro Creek, Morro Rock Beach and Sand Dunes), public facilities to the east (Morro Bay Mutual Water Co), and commercial and recreational areas to the south (the Embarcadero, Coleman Park, and Morro Bay Oyster Company). See **Figure 1-9** for the local surrounding area of the BESS and **Figure 1-10** for a map of the zoning in the area surrounding the BESS Site.

The closest permanent residences, which are located northeast and southeast of the project site, are 500 m (1,640 ft) away from the closest proposed BESS Building, see **Figure 1-11**. The closest schools and daycare centers are approximately 650 m (2,133 ft) away from the corner of the closest BESS Building. As mentioned, the BESS Site is adjacent to open space and recreational areas to the north, west, and south. In addition to residences to the northeast and southeast, there is also an RV park directly north of the proposed BESS Site (Morro Dunes RV Park). The border of the RV Park is about 130 m (427 ft) from the closest BESS Building (with the closest residence in the park at approximately 132 m [433 ft] from the nearest building).

The setback distances for the Enclosure Alternative are similar to those described above. See **Figure 1-12** for an overview of nearby sensitive receptors (i.e., residences) and setback distances. Like the proposed project, the closest sensitive receptor is Morro Dunes RV Park. The border of the RV Park is about 130 m (427 ft) from the closest enclosure (with the closest residence in the park at approximately 135 m [443 ft]).

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[65] EPA. Offsite consequence analysis. https://www.epa.gov/sites/default/files/2013-11/documents/chap-04-final.pdf accessed on January 20, 2023.

[66] USEPA. Risk management program guidance for offsite consequence analysis. https://www.epa.gov/sites/default/files/2013-11/documents/oca-chps.pdf accessed on January 20, 2023.

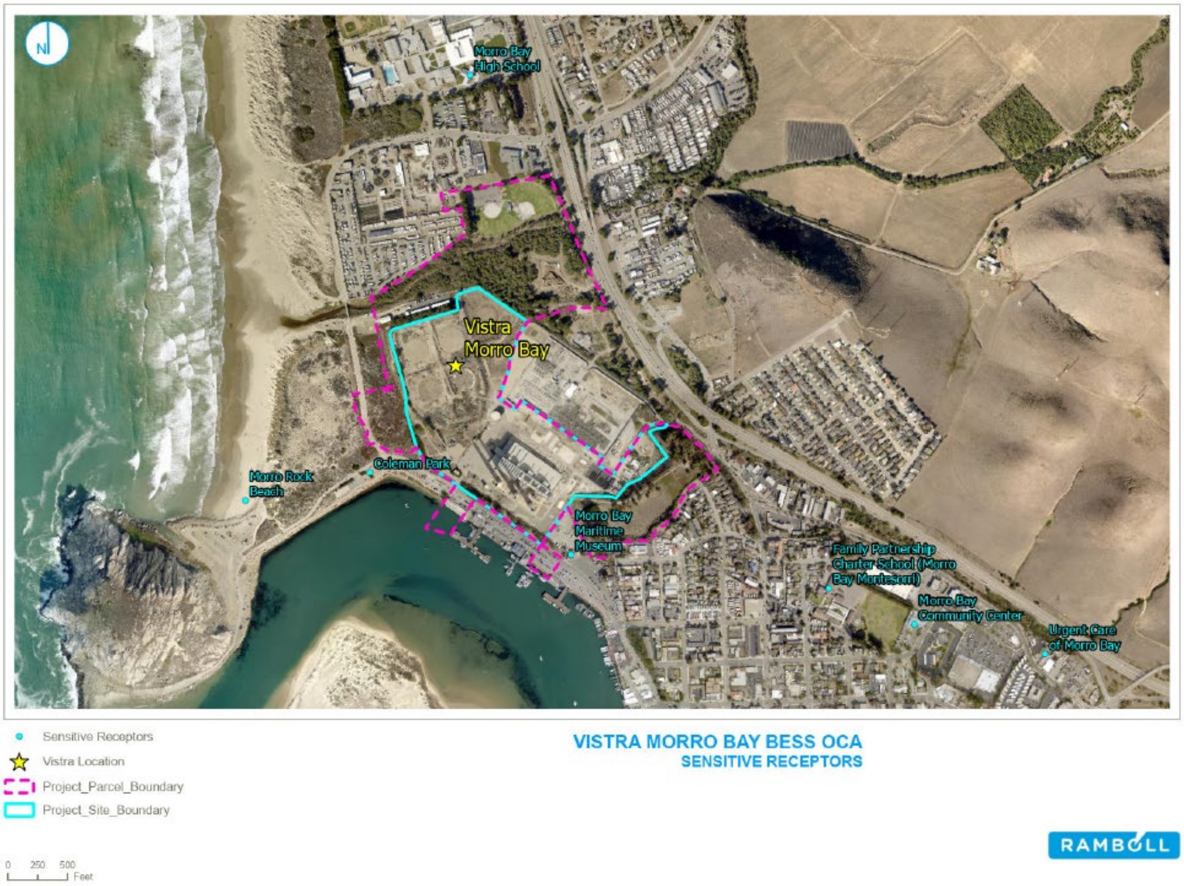

Figure 1-9: Local Surrounding Area of BESS

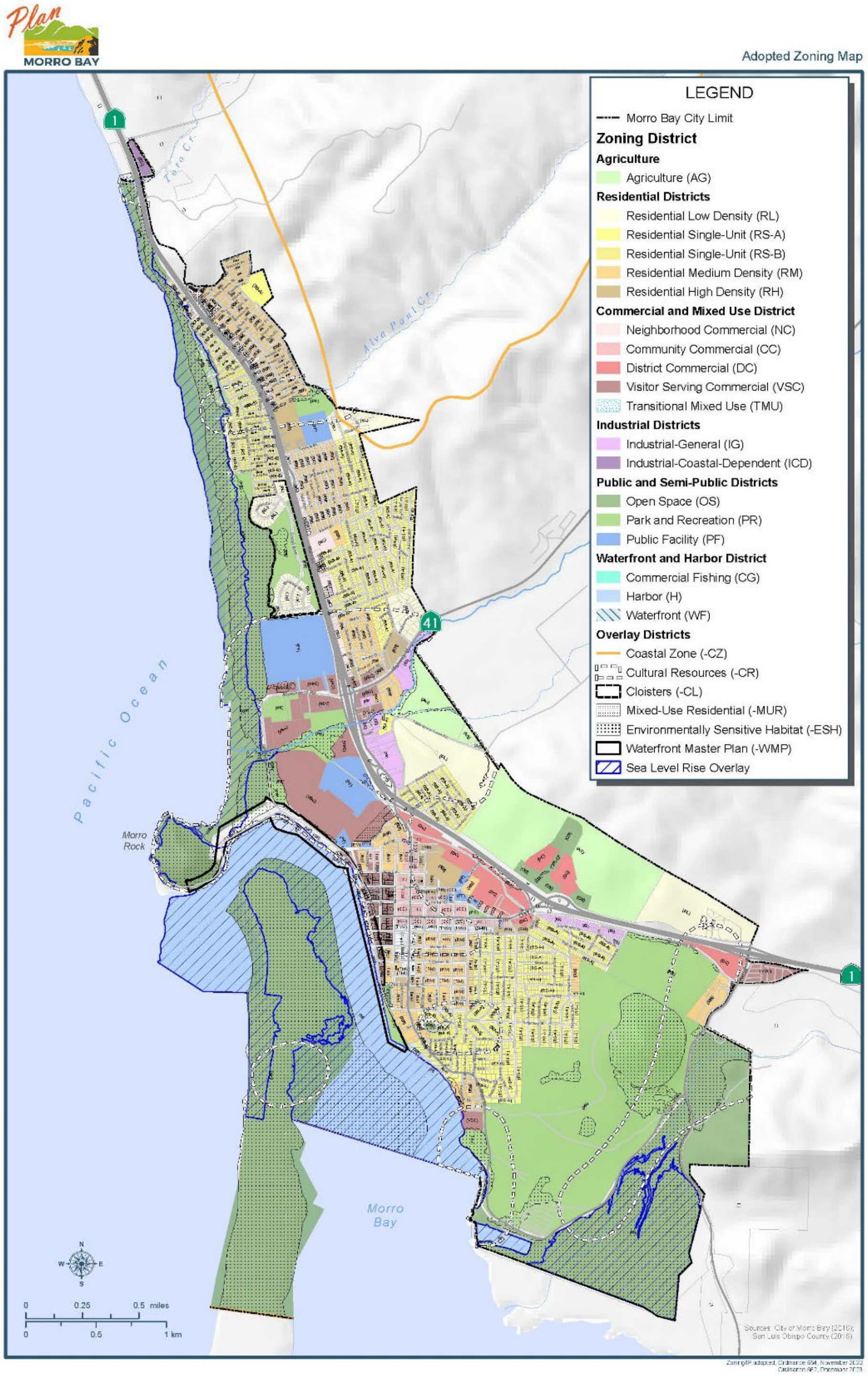

Figure 1-10: Morro Bay Zoning Map[67]

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[67] Accessed from https://www.morrobayca.gov/DocumentCenter/View/18198/2023-Zoning-Map-Amendment, March 18, 2024.

Figure 1-11: Distances to sensitive receptors (Proposed Project)

Figure 1-12: Distances to sensitive receptors (Enclosure Alternative)

1.6.2.2 Meteorological Conditions

Meteorological conditions can affect the location and concentration of airborne emissions and, therefore, how such emissions impact human health and safety. This section describes the meteorological conditions and phenomena considered in this OCA.

Figure 1-13 shows Morro Bay and the location of the two local meteorological stations. The closest meteorological station is San Luis Obispo Airport, located inland approximately 15 miles southeast of the City. The terrain between and around the City and the Airport may indicate that this station is not the most representative of the wind profile in the City itself. A wind rose chart showing the speed and direction of winds at San Luis Obispo Airport is presented in **Figure 1-14**.

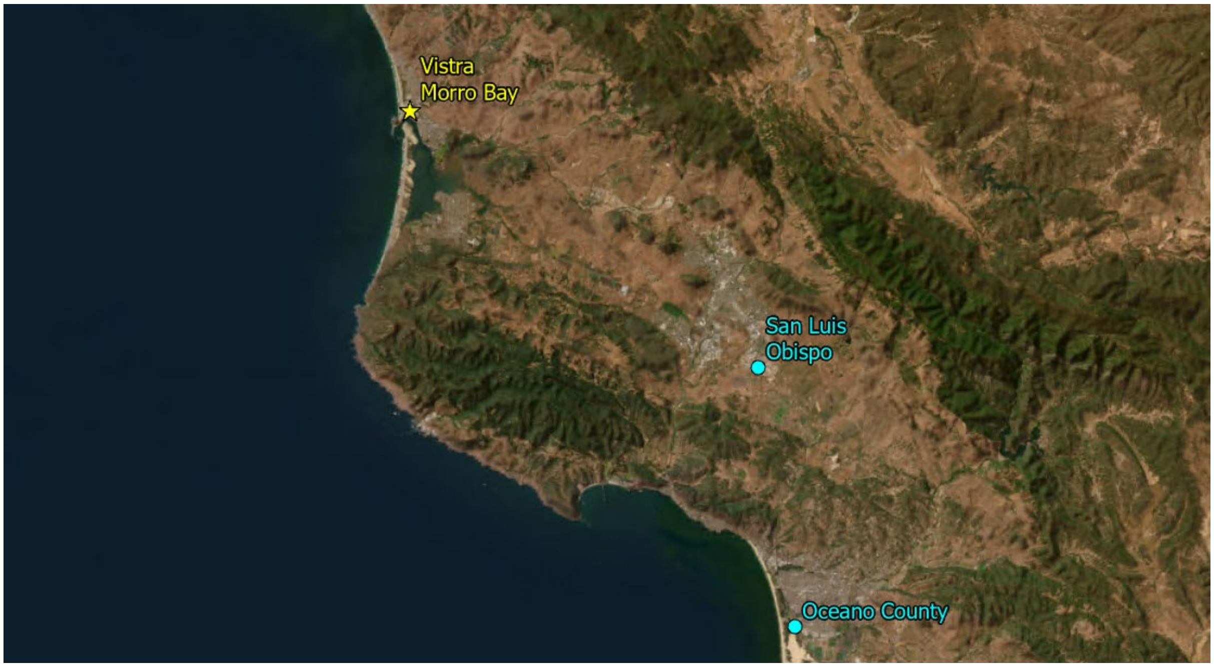

Figure 1-13: Morro Bay and the closest meteorological stations

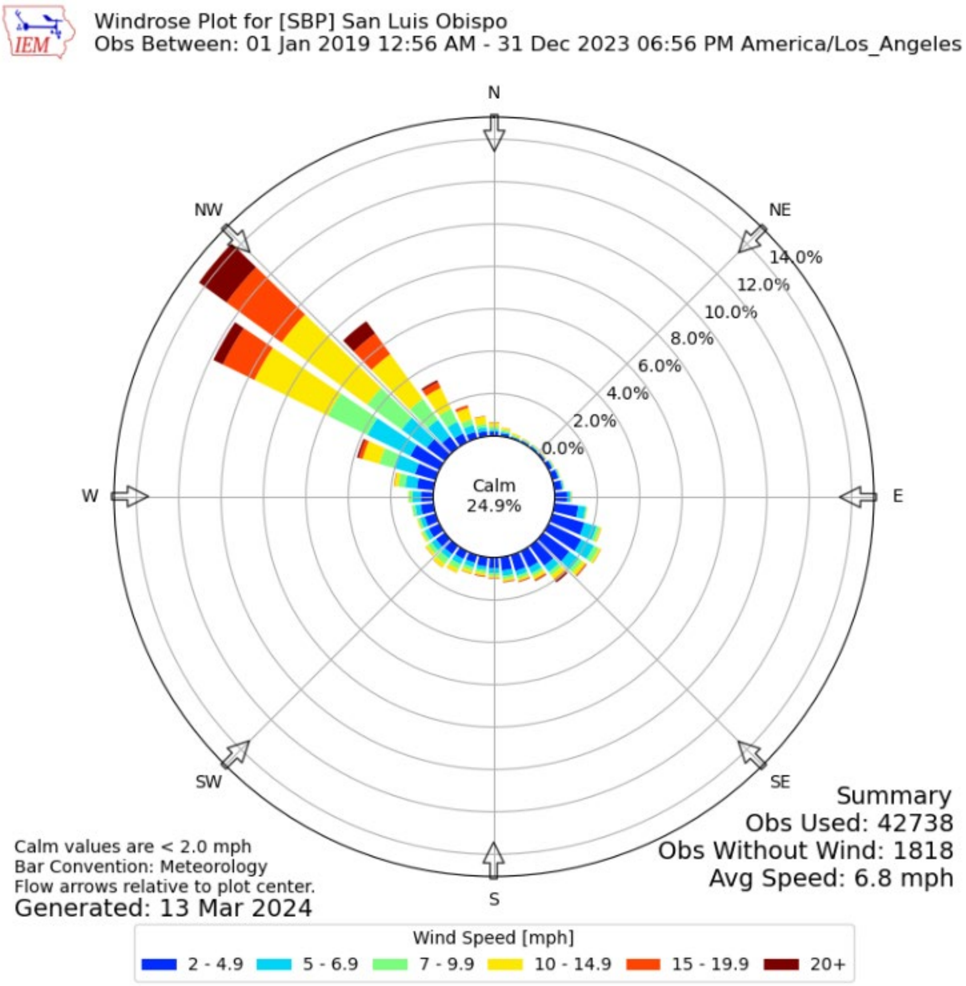

Figure 1-14: Windrose Chart – San Luis Obispo Airport Meteorological Station[68]

The windrose chart shows a strong channeling effect with winds predominantly from the northwest in the direction of the valley where the airport is located. This wind pattern is unlikely to be representative of conditions in Morro Bay, which is on the coast with an unobstructed approach from the west.

The second closest meteorological station is Oceano County, located about 22 miles southeast of the Project Site. Located on the waterfront, which is unshielded from the west, and with elevated terrain in the backdrop to the east, Oceano station has a similar setting to Morro Bay. A windrose chart showing the speed and direction of winds at the Oceano County location is presented in **Figure 1-15**.

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[68] Iowa State University. Iowa Environmental Mesonet. http://mesonet.agron.iastate.edu/sites/windrose.phtml?network=WI_ASOS&station=CWA

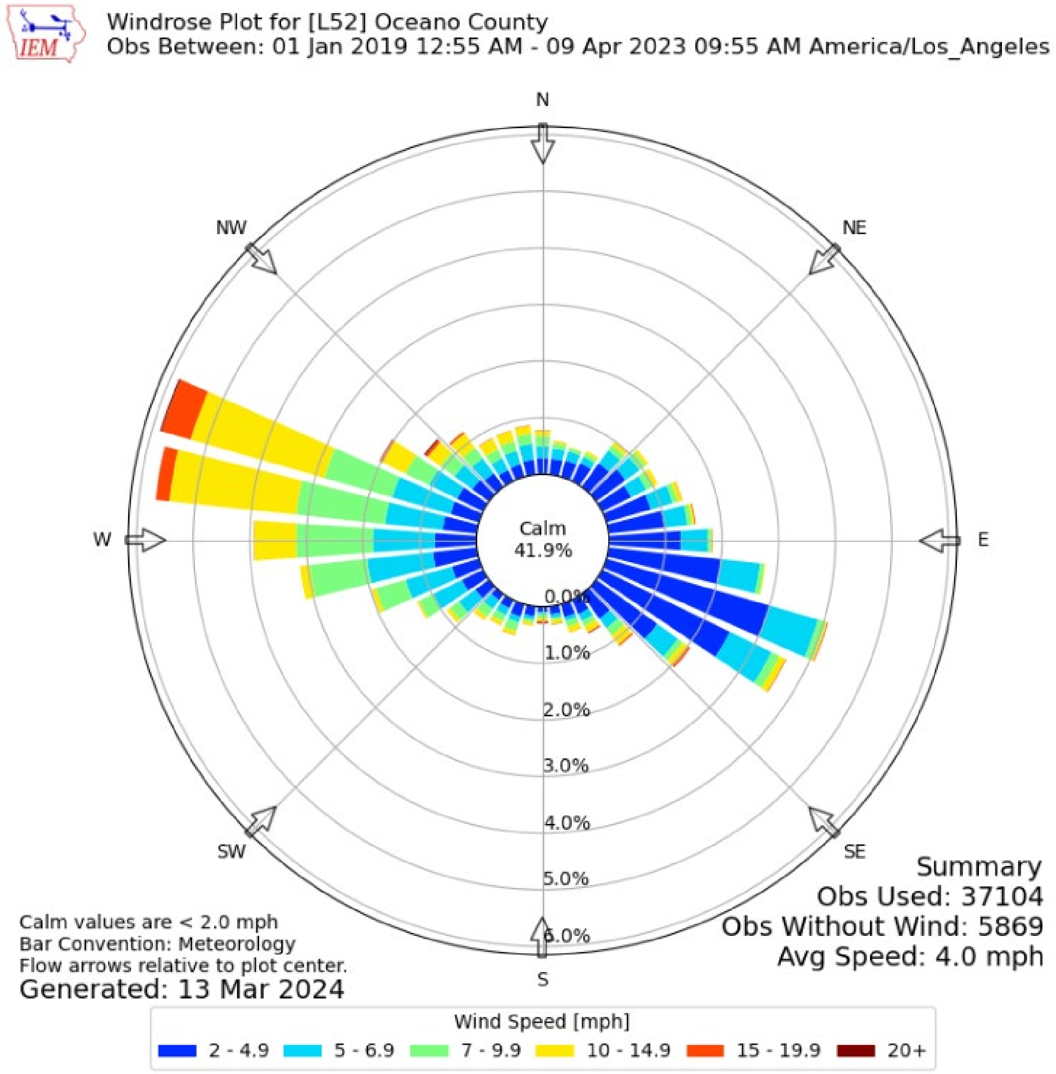

Figure 1-15: Windrose Chart – Oceano County Meteorological Station

This windrose chart shows a more developed approach from the west, which is also expected at Morro Bay, with a new component from the east/south-east. Both meteorological stations show a significant fraction of calm periods, with more than 43% in Oceano County.

This OCA considers meteorological conditions that are likely to result in reasonable worst-case impacts, which occur when ground-level concentrations are at their maximum. For releases near the ground, which would occur with both the Proposed Project and the Enclosures Alternative, this means the plume would be discharged in the inland (unstable) boundary layer with minimal dispersion into higher atmospheric layers. This would result in the highest ground-level concentrations and reflects the worst-case conditions. In this case, the maximum concentrations are likely to occur during stable conditions and at moderate wind speeds.

2. DESIGN AND SAFETY MEASURES

Early BESS facilities were built when codes and industry standards had not yet been updated to address the specific design and safety needs of utility-scale BESS facilities.[69] After reviewing incidents involving those early BESS facilities, codes and standards were updated to address key BESS safety concerns, leading to rapid advances in BESS safety. The significant increase in deployment of BESS has also allowed industry, standard developers, and regulators to learn from past incidents and update codes and testing to make BESS installations safer. A key example is the transition away from "walk-in" enclosures to modular cabinets within enclosures, a design that better limits the propagation of battery fires across a single enclosure. Routine updates and improvements to standards like UL 9540: Standard for Energy Storage Systems and Equipment, and NFPA 855: Standard for the Installation of Stationary Energy Storage Systems, have helped shape industry best practices to improve BESS designs and address safety concerns.[70]

This learning process has resulted in significant improvements in BESS safety.[71] As noted in Section 1.4.1 of this report, the number of BESS facilities has increased dramatically in recent years. However, the fire incident rate has decreased as safety standards developed and improved.[72] The Pacific Northwest National Lab recently calculated the fire incident to be 2.9 percent across the 491 large, utility scale BESS facilities deployed as of April 2023, a rate which includes the operation of early deployments alongside facilities installed to recent codes and standards.[73]

Active and preventative measures to slow or limit thermal runaway through energy storage system design, and to contain its impacts through site configuration, are essential components of an effective risk management approach.[74] These measures include passive design considerations, monitoring equipment, automatic protection and response systems, explosive protection and prevention designs, HVAC and cooling systems, and manual protection tools.

2.1 Facility Safety Design and Applicable Codes and Standards

We understand that Vistra will deploy a multi-tiered safety system at the BESS facility designed by a fire protection architectural and engineering consulting firm to mitigate the risk of and

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[69] EPRI. (Nov. 2023) The Evolution of Battery Energy Storage Safety Codes and Standards 3. https://www.epri.com/research/products/000000003002028521; CPUC. (May 2023) Energy Storage Procurement Study, Attachment F (Safety Best Practices) https://www.cpuc.ca.gov/-/media/cpuc-website/divisions/energy-division/documents/energy-storage/2023-05-31_lumen_energy-storage-procurement-study-report-attf.pdf

[70] EPRI. (Dec. 2023) Safety Implications of Lithium-Ion Chemistries 8 https://www.epri.com/research/products/000000003002028522

[71] EPRI. (Nov. 2023) The Evolution of Battery Energy Storage Safety Codes and Standards 3 https://www.epri.com/research/products/000000003002028521; CPUC. (May 2023) Energy Storage Procurement Study, Attachment F (Safety Best Practices) https://www.cpuc.ca.gov/-/media/cpuc-website/divisions/energy-division/documents/energy-storage/2023-05-31_lumen_energy-storage-procurement-study-report-attf.pdf

[72] EPRI. (Nov. 2023) The Evolution of Battery Energy Storage Safety Codes and Standards 3-4 https://www.epri.com/research/products/000000003002028521

[73] Pacific Northwest National Laboratory. (Oct. 2023) Energy Storage in Local Zoning Ordinances 4 https://www.pnnl.gov/main/publications/external/technical_reports/PNNL-34462.pdf

[74] M.G.Aydin and C.O Aydin. 2023. California Public Utilities Commission Energy Storage Procurement Study. Lumen Energy Strategy, LLC. Prepared for the California Public Utilities Commission. May 31, 2023. ATTACHMENT F: SAFETY BEST PRACTICES www.lumenenergystrategy.com/energystorage

consequences from a fire. This system will prioritize passive design measures to prevent fire, deflagration, and explosions because passive designs will function even in a worst-case scenario to prevent or slow the spread of any fire. Active measures, as discussed below, will also be used. However, this OCA assumes these systems fail in order to model the consequences of a maximum credible fire event under worst-case conditions.

2.1.1 Fire Code and Industry Standards

The BESS facility will be required to meet the requirements of the California Fire Code.[75] We understand that Vistra has also committed to complying with any applicable industry standards that may be more stringent or fire-protective than the provisions in the Fire Code. These industry standards include:

- NFPA 13 Standard for the Installation of Sprinkler Systems;
- NFPA 15 Standard for Water Spray Fixed Systems for Fire Protection;
- NFPA 68 Standard on Explosion Protection by Deflagration Venting;
- NFPA 69 Standard on Explosion Prevention Systems;
- NFPA 72 National Fire Alarm and Signaling Code;
- NFPA 855-2023 – Energy Storage Management System;
- UL 9540 – Energy Storage Systems and Equipment.

Modules selected for installation will undergo testing to Standard UL 9540A as required by the California Fire Code in Sections 1207.3.1 and 1207.1.5. To assess risks at a BESS level, UL developed Standard UL 9540A for the observation and evaluation of behavior in an actual thermal runaway situation. This is a destructive lab test in which thermal runaway is instigated and observed—at the cell level, module level, unit/rack level, and installation level. A favorable test outcome is essentially a thermal runaway that self-extinguishes without significant propagation, flaming, or explosion. Less favorable outcomes provide guidance for additional risk mitigation and management that may be needed to meet the UL standard and comply with fire codes and other safety objectives. In sum, the test assesses the ability of an individual cell and an individual module to contain a thermal runaway event to that cell or module. We understand that Vistra will select modules whose testing performance indicates that the risk of propagation of thermal runaway to nearby cells, modules, or racks is minimized.

BESS facilities also incorporate backup fire suppression systems. The backup system for fire suppression incorporates a meticulously designed network of water fire protection pipes and sprinklers. The quantity, diameter, and strategic placement of these components are all in strict adherence to relevant design requirements, ensuring comprehensive coverage and effectiveness in the event of a fire. Additionally, the installation of the sprinkler systems conforms to established standards, ensuring reliability and functionality when needed most. To facilitate emergency responses and enhance the system's efficiency, a fire water connection is conveniently reserved outside the cabinet. This setup ensures that, in the event of a fire, the backup system is primed for immediate activation, providing an essential layer of safety and protection.

Explosion control required by NFPA 855 can be achieved by following either NFPA 68 (focusing on deflagration venting) or NFPA 69 (focusing on explosion prevention measures).[76] Under NFPA

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[75] Title 24 California Code of Regulations Section 1207, Electrical Energy Storage Systems (ESS).

[76] EPRI (2023) The Evolution of Battery Energy Storage Safety Codes and Standards. 2023 White Paper. https://www.epri.com/research/products/000000003002028521

68, deflagration venting—which creates a pathway for rapidly expanding gases to exit the enclosure—must be provided based on UL Test Method 9540A or other approved test data. Vents must be designed to limit the maximum pressure developed within the enclosure during a vented deflagration to be less than the enclosure strength by a sufficient margin of safety to prevent a catastrophic failure.[77] If implementing an explosion prevention system according to NFPA 69, the combustible concentration must be maintained at or below 25% of the lower flammability limit (LFL) for all foreseeable variations in operating conditions and material loadings. One option for meeting these requirements is by ventilation or air dilution.[78]

2.1.2 Emergency Response Plan and Hazard Mitigation Analysis

Vistra will also develop an emergency response plan, as required by California Public Utilities Code Section 761.3(g) and implementing guidelines and regulations currently under development by the CPUC. This plan will establish the response procedures for an equipment malfunction or failure; develop procedures to ensure the safety of surrounding residents, properties, emergency responders, and the environment; create notification and communication procedures between the facility and local emergency management agencies; and be developed in consultation with the local emergency management agencies.

2.2 Passive Design Measures

The specific design of the facility has not yet been selected given the ongoing CEQA process, but the application of the requirements of the California Fire Code, industry standards, and Vistra's proposal will ensure that passive design measures are incorporated into the project to limit and slow the spread of any thermal runaway or fire event.

Under the Enclosure Alternative, each enclosure would be encased within a non-combustible casing, as required by Section 1207.3.5 of the California Fire Code (CFC). Each enclosure will also be spaced at least 10 feet from any other enclosures, with greater distances in spacing possible depending on final site design and heat-mapping by the fire protection architectural and engineering consulting firm. This spacing, along with each enclosures' fire protection and safety systems, would ensure that any fire event in a single enclosure is limited to that enclosure. Analyses performed of past fire events show this sort of passive design measure can be effective in limiting the spread of BESS fires.[79] Enclosure spacing will also ensure the local fire department can access an enclosure in any emergency response scenario.

Within each block or enclosure, individual racks (or cabinets) of modules would be separated by noncombustible barriers, as required by Section 1207.3.5 of the CFC. These barriers, which are analogous to firewalls in buildings, would be designed to prevent the spread of any fire from one rack to another and would slow the spread of any such fire.

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[77] Conzen et al. (2023) Lithium ion battery energy storage systems (BESS) hazards. Journal of Loss Prevention in the Process Industries, 81 https://doi.org/10.1016/j.jlp.2022.104932

[78] Conzen et al. (2023) Lithium ion battery energy storage systems (BESS) hazards. Journal of Loss Prevention in the Process Industries, 81 https://doi.org/10.1016/j.jlp.2022.104932; Kapahi et al. (2023) Performance-based assessment of an explosion prevention system for lithium-ion based energy storage system. Journal of Loss Prevention in the Process Industries, 82 https://doi.org/10.1016/j.jlp.2023.104998

[79] Pacific Northwest National Laboratory. (Oct. 2023) Energy Storage in Local Zoning Ordinances 6-7 https://www.pnnl.gov/main/publications/external/technical_reports/PNNL-34462.pdf

The enclosure for each module will comply with UL 9540's requirement in Section 7.1 that the enclosure be comprised of non-combustible materials. Each module and cell within each module will be separated from the other modules and cells by thermal layers, designed to isolate thermal runaway events to an initiating module and therefore limit its spread to that module.[80] The capacity of the overall system to limit such spread is tested by the use of UL 9540A, discussed above. Use of UL 9540-compliant modules tested to UL 9540A is required by the CFC (in Sections 1207.3.1 and 1207.1.5), and therefore must be used by the facility.

2.3 Active Design Measures

The BESS facility will include active design measures intended to prevent or limit any fire incident. The active design measures included will be determined prior to construction during the final project design, and decisions will be made in coordination with safety experts and the Morro Bay Fire Department. Some measures are fixed by the California Fire Code, while Vistra has committed to several additional measures.

For example, the facility will include systems to continually monitor electrical and thermal parameters, as well as the presence of any gas and smoke, to allow for early response actions, including by local first responders, if necessary. Early warning fire detection systems will include gas and smoke detection spaced at appropriate distances. Enclosures will include HVAC systems to maintain temperatures and avoid thermal runaway.

The CFC Section 1207.3.4 further requires the use of an energy storage management system that monitors and balances cell voltages, currents, and temperatures to ensure they remain within manufacturer specifications. This system must be able to disconnect individual modules or otherwise place it in a safe condition if a hazardous condition is detected. The battery management system (BMS) provides the primary thermal runaway protection and is one of the most important barriers. Therefore, BESS safety standards, such as NFPA 855, require that the BMS is evaluated together with the batteries as part of the evaluation to UL 1973 or UL 9540. In a UL 9540 listed BESS, the BMS monitors, controls, and optimizes the performance of battery modules in the BESS and disconnects the modules from the system in the event of abnormal conditions. In addition, the BMS provides charge and discharge management of the batteries. In case of under voltage or overvoltage, over-temperature or overcurrent conditions, the BMS will alarm and then limit the charge and discharge current or power. Under emergency conditions, the BMS will cease operations of and electrically disconnect each battery enclosure.

NFPA 855, discussed above, further requires BESS to be equipped with a smoke-detection or radiant energy-sensing system. Early detection of an incident can be accomplished by detecting vent gases, including carbon monoxide, carbon dioxide, hydrogen, and flammable hydrocarbons. Where gas detection is used to activate a combustible gas concentration reduction system (for compliance with NFPA 69), the detectors must be securely powered in standby mode for a minimum of 24 hours, followed by 2 hours in alarm.[81]

While active design measures would limit or prevent the spread of any fire in most situations, this analysis conservatively assumes all active measures fail. Because passive design measures are intrinsic to the facility (i.e., they represent physical objects such as spacing or a firewall that

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[80] ANSI/CAN/UL 9540:2023. Standard for Safety. Energy Storage Systems and Equipment.

[81] EPRI. (2023) The Evolution of Battery Energy Storage Safety Codes and Standards. 2023 White Paper. https://www.epri.com/research/products/000000003002028521

will operate even in a worst-case scenario), their impact on fire safety is included in the analysis.[82]

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[82] EPA allows the use of passive controls when calculating its worst case scenarios for RMP (see 81 FR 13663, March 14, 2016)

3. POTENTIAL AIR EMISSIONS

3.1 Introduction

The nature of air emissions from fires at BESS facilities depends on a number of factors, including the types of batteries used, their materials and components, their energy and power density, their state of charge (SOC), battery age, combustion temperature, and ambient meteorological conditions. **Figure 3-1** provides a breakdown of the typical materials used in the fabrication of LiB nickel manganese cobalt (NMC) battery system. The lithium metal oxides referenced in **Figure 3-1** includes oxygen, manganese, cobalt, nickel, and lithium. While there is limited information on the materials used for battery casings, the information suggests that a variety of materials have been used, including nickel-coated steels, aluminum, and polymers (e.g., polypropylene).[83] In addition, there is some evidence that additional materials such as PVC may be used in small-scale applications.[84] Various halide-containing polymers, including chlorinated polymers, may also be used in the binder, separator, and packaging of the battery.[85]

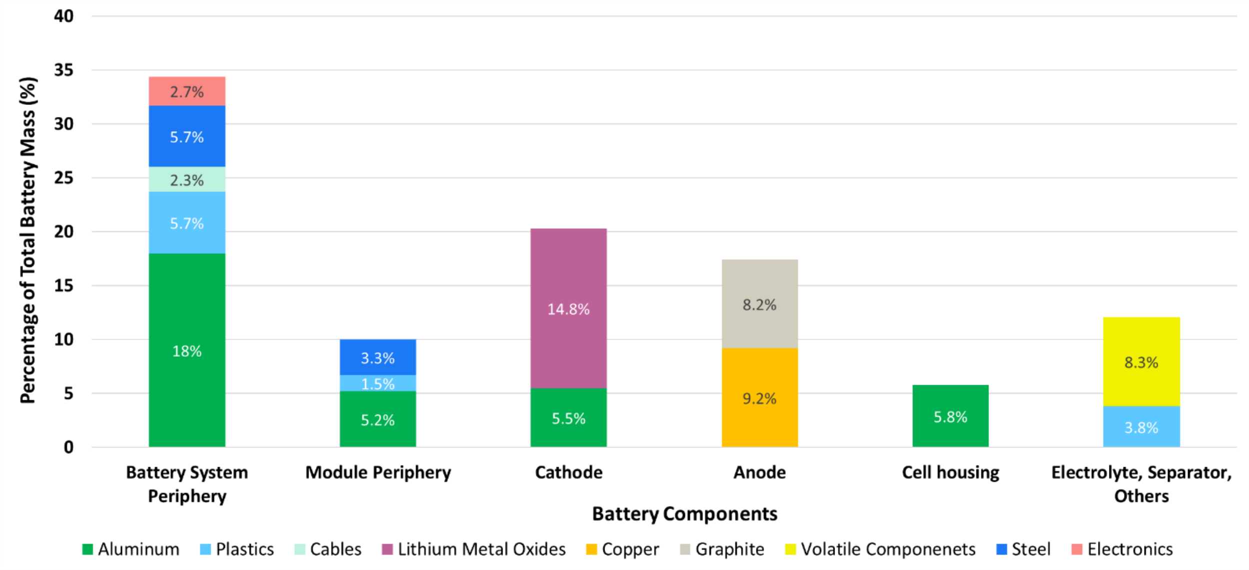

Figure 3-1: Generic composition of a LiB nickel manganese cobalt (NMC) battery system[86,87,88]

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[83] Evesmart. Lithium-ion batteries Can and Casing. https://evsemart.com/blog/lithium-ion-battery/lithium-ion-batteries-can-and-casing#:~:text=In%20addition%20to%20the%20outer,by%20nickel%20to%20the%20steel

[84] RBR. Battery Pack, 14.4V, 2-3-2, 56 D-Cells Lithium. https://rbr-global.com/wp-content/uploads/2019/05/0002542revA.pdf

[85] Ribière et al. (2012) Investigation on the fire-induced hazards of Li-ion battery cells by fire calorimetry, Energy Environ. Sci. 5, 5271–5280. https://doi.org/10.1039/C1EE02218K

[86] Gerold E. et al. (2021) Critical Evaluation of the Potential of Organic Acids for the Environmentally Friendly Recycling of Spent Lithium-Ion Batteries. Recycling, 7. https://www.doi.org/10.3390/recycling7010004

[87] Diekman et al. (2017). Ecological Recycling of Lithium-Ion Batteries from Electric Vehicles with Focus on Mechanical Processes. Journal of the Electrochemical Society, 164 (1) A6184-A6191. https://iopscience.iop.org/article/10.1149/2.0271701jes/pdf

[88] Buchert, M., and Sutter, J. (2015) Ökobilanzen zum Recyclingverfahren LithoRec II für Lithium-Ionen-Batterien. https://www.erneuerbar-mobil.de/sites/default/files/publications/endbericht-kobilanzen-zum-recyclingverfahren-lithorec-ii-fuer-lithium-ionen-batterien_1.pdf

Most of these constituents can potentially contribute to the airborne emissions from BESS fires. Airborne emissions and their speciation (i.e., the chemical form in which they could be emitted) depend on a number of factors such as the battery's SOC, the specific components and chemistry of the battery, the type of stress (mechanical, thermal, electrical) that initiated the failure event, the exact nature of the failure cause (method of mechanical abuse, rate of heating or overcharge, etc.), if or when the vent gases are ignited, or availability of oxygen.[89] These factors also govern material partitioning between phases (gas, liquid aerosols, or solid particulate).

Emissions from battery fires are closely related to the mass (weight) change from the battery before and after the fire. This is also referred to as "mass loss." Some studies suggest that the relative mass loss of cell material during fires does not seem to vary significantly based on the intensity or duration of fires, or the conditions of the batteries.[90,91] The most common estimate of a typical fraction of mass lost (under experimental or testing conditions) during combustion is about 18%.[92] This is within the range of the electrolyte mass fraction in LiBs, which ranges between approximately 10% and 22.5%,[93,94,95] and suggests that the mass loss during battery burning is driven primarily by the loss of electrolyte.

There seems to be a consensus on the typical dynamics of thermal runaway and emissions associated with it. The early stage of the battery failure is associated with the accumulation of gases, which is the product of the heating and volatilization of the liquid electrolyte. The gases include solvent vapors, carbon dioxide (CO_2), carbon monoxide (CO), water vapor, hydrogen fluoride (HF), lithium fluoride (LiF), and hydrogen (H_2). Gas venting is commonly associated with visible white plumes, containing "H_2, SO_2, NO_2, HF, HCl, CO, CO_2, droplets of organic solvent (giving the white color) and a large range of small chain alkanes and alkenes."[96] If not detected or addressed in time, the accumulation of gases could continue to the point where gases breach

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[89] Wang et al. (2019) Thermal runaway and fire behaviors of large-scale lithium-ion batteries with different heating methods. Journal of Hazardous Materials, 379, 120730. https://doi.org/10.1016/j.jhazmat.2019.06.007; Zhang et al. (2019) Quantitative identification of emissions from abused prismatic Ni-rich lithium-ion batteries. eTransportation, 2, 100031. https://doi.org/10.1016/j.etran.2019.100031; Ribière et al. (2012) Investigation on the fire-induced hazards of Li-ion battery cells by fire calorimetry, Energy Environ. Sci. 5, 5271–5280. https://doi.org/10.1039/C1EE02218K; Swiss Federal Laboratory for Materials Science and Technology. (2020) Elektromobilität und Tunnelsicherheit – Gefährdungen durch Elektrofahrzeugbrände. https://plus.empa.ch/images/2020-08-17_Brandversuch-Elektroauto/AGT_2018_006_EMob_RiskMin_Unterird_Infrastr_Schlussbericht_V1.0.pdf

[90] DNV-GL SUPPORT FOR APS RELATED TO MCMICKEN THERMAL RUNAWAY AND EXPLOSION McMicken Battery Energy Storage System Event Technical Analysis and Recommendations, Available at: https://coaching.typepad.com/files/mcmicken.pdf

[91] Ribière, P. et al. (2012) Investigation on the fire-induced hazards of Li-ion battery cells by fire calorimetry, Energy Environ. Sci. 5, 5271–5280. https://doi.org/10.1039/C1EE02218K

[92] DNV-GL SUPPORT FOR APS RELATED TO MCMICKEN THERMAL RUNAWAY AND EXPLOSION McMicken Battery Energy Storage System Event Technical Analysis and Recommendations, Available at: https://coaching.typepad.com/files/mcmicken.pdf

[93] Golubkov et al. (2014) Thermal-runaway experiments on consumer Li-ion batteries with metal-oxide and olivin-type cathodes", RSC Adv. https://pubs.rsc.org/en/content/articlelanding/2014/ra/c3ra45748f

[94] Dai Q. *et. al.* (2019). EverBatt: A Closed-loop Battery Recycling Cost and Environmental Impacts Model", Argonne National Laboratory. Available at: https://publications.anl.gov/anlpubs/2019/07/153050.pdf

[95] Wang Z. *et. al.* (2018). Evaluating the thermal failure risk of large-format lithium-ion batteries using a cone calorimeter. https://journals.sagepub.com/doi/10.1177/0734904118816616

[96] Mrozik et al. (2021) Environmental impacts, pollution sources and pathways of spent lithium-ion batteries. Energy & Environmental Science, 14, 6099. https://doi.org/10.1039/D1EE00691F

the insulating polymer membrane separator (which separates the electrode layers as shown in **Figure 1-5** in Section 1 of this report) and are vented from the battery cell. At this point the gases could ignite and result in a fire, and in certain cases, an explosion.

After ignition, the battery will continue to emit substances, which are then subject to thermal oxidation. The final speciation of the vented gases and battery constituents will depend on various factors discussed previously and can present as jet-like flames and/or sparks.[97] During a sustained thermal event, the battery may also emit heavy, black smoke, which is typically associated with particulate emissions.[98] In addition, some studies relying on indirect observations (e.g., from the samples of surfaces and water adjacent to a battery fire experiment) indicate that LiB fires may also produce polyaromatic hydrocarbons, polychlorinated biphenyls, and dioxins/furans.[99]

Table 3-1 summarizes the different species produced during LiB fires, as reported across different studies.

Table 3-1: Substances associated with or measured during one or more stages of LiB failure events (includes vent gases and emissions from fires)

State	Substances
Gases[100]	Non-Hydrocarbons: carbon dioxide, carbon monoxide, hydrogen, water, nitrogen oxides, sulfur dioxide Fluorinated Compounds: hydrogen fluoride, phosphorous trifluoride, phosphorous pentafluoride, phosphoryl fluoride, lithium fluoride (solid), fluoroethane, fluoroethane Chlorinated Compounds: hydrogen chloride Hydrocarbons Alkanes: methane, ethane, propane, butane, pentane Alkenes: ethene, propene, , 1-butylene, 2-methyl propene , trans-2-butene , cis-2-butene , 1-pentene , cis-2-pentene , trans-2-pentene , 2-methyl-1-butene , 2- methyl-2-butene , 3-methyl-1-butene , 2-methyl-1- pentene , 2,4-Dimethyl-1-Heptene , 1,3-Butadiene Alkynes: Ethyne, Propyne

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[97] Wang et al. (2019) Thermal runaway and fire behaviors of large-scale lithium-ion batteries with different heating methods. Journal of Hazardous Materials, 379, 120730. https://doi.org/10.1016/j.jhazmat.2019.06.007

[98] Mrozik et al. (2021) Environmental impacts, pollution sources and pathways of spent lithium-ion batteries. Energy & Environmental Science, 14, 6099. https://doi.org/10.1039/D1EE00691F

[99] Held et al. (2022). Thermal runaway and fire of electric vehicle lithium-ion battery and contamination of infrastructure facility. Renewable and Sustainable Energy Reviews, 165, 112474. https://doi.org/10.1016/j.rser.2022.112474

[100] Zhang et al. (2019) Quantitative identification of emissions from abused prismatic Ni-rich lithium-ion batteries. eTransportation, 2, 100031. https://doi.org/10.1016/j.etran.2019.100031; Mrozik et al. (2021) Environmental impacts, pollution sources and pathways of spent lithium-ion batteries. Energy & Environmental Science, 14, 6099. https://doi.org/10.1039/D1EE00691F; Swiss Federal Laboratory for Materials Science and Technology. (2020) Elektromobilität und Tunnelsicherheit – Gefährdungen durch Elektrofahrzeugbrände. https://plus.empa.ch/images/2020-08-17_Brandversuch-Elektroauto/AGT_2018_006_EMob_RiskMin_Unterird_Infrastr_Schlussbericht_V1.0.pdf; Premnath et al. (2022) Detailed characterization of particle emissions from battery fires. Aerosol Science and Technology 56(4), 337-354. https://doi.org/10.1080/02786826.2021.2018399

	Carbonate Esters: dimethyl carbonate, diethyl carbonate, methyl ethyl carbonate (electrolyte/solvent vapor) Aromatics: Benzene, Toluene, Xylene, and Styrene Other: HCN, Dimethyl Ether, Methyl Formate, Ethanol, Methanol
Particulate (incl. aerosols)	Elemental carbon/carbon black, nickel, oxygen, copper, aluminum, cobalt, manganese lithium, sulfur, chlorine, hydrogen, fluorine, potassium, phosphorous, iron, zirconium, strontium, sodium, calcium, iodine, bromine, titanium, chromium, barium, arsenic, vanadium, tin, zinc, magnesium, antimony, silicon, boron, molybdenum

3.2 Estimating Emissions from a Potential Fire

There have been a considerable number of studies identifying emission byproducts from battery thermal runaways and fires, but only a limited number of studies attempt to quantify those emissions.[101,102,103,104] Most of the studies that quantified emissions focused on gaseous products, while a smaller number of studies attempted to also quantify particulate and aerosol emissions.[105,106,107,108] Quantitative data for the species of interest (hazardous air contaminants and toxics) from available studies is set forth in **Table 3-2** and **Table 3-3**, followed by a

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[101] Ribière, P. et al. (2012) Investigation on the fire-induced hazards of Li-ion battery cells by fire calorimetry, Energy Environ. Sci. 5, 5271–5280. https://doi.org/10.1039/C1EE02218K; Larsson et al. (2017) Toxic fluoride gas emissions from lithium-ion battery fires. Scientific reports 7(1), 10018. https://www.nature.com/articles/s41598-017-09784-z; Larsson et al. (2014) Characteristics of lithium-ion batteries during fire tests. Journal of Power Sources, 271, 414-420. https://doi.org/10.1016/j.jpowsour.2014.08.027; Mrozik et al. (2021) Environmental impacts, pollution sources and pathways of spent lithium-ion batteries. Energy & Environmental Science, 14, 6099. https://doi.org/10.1039/D1EE00691F; Zhang et al. (2019) Size distribution and elemental composition of vent particles from abused prismatic Ni-rich automotive lithium-ion batteries. Journal of Energy Storage, 26, 100991. https://doi.org/10.1016/j.est.2019.100991

[102] Larsson et al. (2017) Toxic fluoride gas emissions from lithium-ion battery fires. Scientific reports 7(1), 10018. https://www.nature.com/articles/s41598-017-09784-z accessed on December 23, 2022.

[103] SP Technical Research Institute of Sweden. Investigation of fire emissions from Li-ion batteries. http://www.diva-portal.org/smash/get/diva2:962743/FULLTEXT01.pdf accessed on December 23, 2022.

[104] MPDI. (2016) Toxic gas emissions from Damaged Lithium Ion Batteries – Analysis and Safety Enhancement Solution. https://www.mdpi.com/2313-0105/2/1/5 accessed on December 23, 2022.

[105] Zhang et al. (2019) Quantitative identification of emissions from abused prismatic Ni-rich lithium-ion batteries. eTransportation, 2, 100031. https://doi.org/10.1016/j.etran.2019.100031; Zhang et al. (2019) Size distribution and elemental composition of vent particles from abused prismatic Ni-rich automotive lithium-ion batteries. Journal of Energy Storage, 26, 100991. https://doi.org/10.1016/j.est.2019.100991

[106] Mellert L et al., "Elektromobilität und Tunnelsi-cherheit – Gefährdungen durch Elektrofahrzeugbrände", June 2018.

[107] Ribière, P. et al. (2012) Investigation on the fire-induced hazards of Li-ion battery cells by fire calorimetry, Energy Environ. Sci. 5, 5271–5280. https://doi.org/10.1039/C1EE02218K; Larsson et al. (2017) Toxic fluoride gas emissions from lithium-ion battery fires. Scientific reports 7(1), 10018. https://www.nature.com/articles/s41598-017-09784-z; Larsson et al. (2014) Characteristics of lithium-ion batteries during fire tests. Journal of Power Sources, 271, 414-420. https://doi.org/10.1016/j.jpowsour.2014.08.027; Mrozik et al. (2021) Environmental impacts, pollution sources and pathways of spent lithium-ion batteries. Energy & Environmental Science, 14, 6099. https://doi.org/10.1039/D1EE00691F; Zhang et al. (2019) Size distribution and elemental composition of vent particles from abused prismatic Ni-rich automotive lithium-ion batteries. Journal of Energy Storage, 26, 100991. https://doi.org/10.1016/j.est.2019.100991

[108] Zhang et al. (2019) Quantitative identification of emissions from abused prismatic Ni-rich lithium-ion batteries. eTransportation, 2, 100031. https://doi.org/10.1016/j.etran.2019.100031; Zhang et al. (2019) Size distribution and elemental composition of vent particles from abused prismatic Ni-rich automotive lithium-ion batteries. Journal of Energy Storage, 26, 100991. https://doi.org/10.1016/j.est.2019.100991

summary of the relevant findings and conclusions from those studies. All the studies reviewed involved experimental investigation where fires were induced in a controlled environment. We did not identify any work that reported systematic observations or measurements of downwind concentrations of contaminants from actual fires, as opposed to laboratory fires or those specifically created for testing.

Table 3-2: Summary of Emission Factors Reported or Derived from Different Studies (mg/kg basis)

Study	Battery/ Module Energy Capacity Tested [Wh]	Battery Cell Mass [kg]	Emission Factor [mg/kg of battery]				Additional Information
			HF	HCl	CO	HCN	
1	11	0.095	4,095-8,221	179-347	737-21,053		Other species tested or observed in the study include NO, SO_2, CO_2, THC.
2	92-124	0.64-1.23	2,973-11,320				N/A
3	10-70	Not reported					HF and POF_3 emission factors reported in mg/Wh. Battery mass tested not provided to derive with confidence emission factors per battery mass basis.
4	182.5	0.87		<DL	33,180		F quantified in solids only. A large number of speciated VOCs quantified including 1, 3 Butadiene and C_6H_6; and a number of elements within the PM sample (C, Mn, Li, Co, Ni, Cu, Al, V, Cr, etc.)
5	4,150	2.4	<17-108		2,643-6,296		Additional species quantified: Benzene, Toluene, Xylene, Styrene, metal compounds including Mn, Li and Co. Additional species reported but without sufficient information to derive emission factors include NO, PH_3, H_3PO_4, F aerosol, NO_2, CO_2, TVOC, aromatics.
6	9	0.075	>253		517		Cell level tests. Species tested include PF_3, DMC, CO_2, EMC, H_2, C_2H_4, C_2H_5F, CH_3OCH_3, CH_3OCHO, CH_4, CH_3F, CH_3OH, C_2H_5OH, C_2H_6, C_3H_6, etc.
7	113-283	1.18-1.925	883-3,559				Other species quantified include CO_2 and VOCs. Additional species identified include CO, DEC, DMC, EMC.
8	150-8,400	Not reported					Gas compounds quantified: HF, HCl, HBr, CO, CO_2, SO_2, NO, THC, PAHs, PM and elements within the PM (Ni, Li, Co). For an estimated battery pack mass of 70 kg, derived emission factors for HF, HCl and CO would be within the range of those reported in this table.
9	336-360	~ 2.0	ND–1,431	633-2,575	4,072-33,761		Additional species tested include CH_4, C_2H_4, C_3H_6, CO_2, H_2, NH_3.
10	Not reported	Approx. 0.5–6.5	1,253	1,699	1,440	1,253	Emission rate in g/s per 30-minute burn event reported as an average or representative value derived from multiple tests and cells of different types and sizes. Information on the battery mass in individual tests not provided. Emission factors estimated from the reported emission rates and the cell mass range considered in the study (approximately 0.5 kg/cell to 6.5 kg/cell). Emission factors in mg/kg battery derived conservatively assuming the reported emission rate in g/s per 30 min was released from the smallest cell (0.5 kg).
11	Not applicable	Not applicable	2,816-9,520		304-2,688	64	No actual battery tests. Evaluation of emissions from burning various LiPF6 and LiFSI-based electrolytes. Additional species quantified include CO_2, POF_3, NO, SO_2, C_2H_4, CH_4, C_2H_2, HCOH, THC, SiF_4, soot. Emission factors derived assuming 16% mass share of electrolyte in battery.
12	411	0.039-0.044			1,723-46,228		Additional species tested include CO_2, H_2, CH_4, C_2H_4, and C_2H_6.
13	Varied	Not reported					Information on the battery mass tested not provided to derive with confidence emission factors per battery mass basis. Species tested include HF, HCl, HCN, CO_2, NO_2, CH_4, C_2H_4, C_2H_6, C_3H_8, CH_3OH, C_2H_5OH, Benzene, and Toluene.

1: Ribière, P. et. al., Investigation on the fire-induced hazards of Li-ion battery cells by fire calorimetry, Energy Environ. Sci. 5 (2012) 5271–5280.
2: F. Larsson, P. Andersson, P. Blomqvist, A. Lorén, B.E. Mellander, Characteristics of lithium-ion batteries during fire tests, J. Power Sources 271 (2014) 414–420.
3: F. Larsson, P. Andersson, P. Blomqvist, B.-E. Mellander, Toxic fluoride gas emissions from lithium-ion battery fires, Sci. Rep. 7 (2017) 10018.
4: Y. Zhang et al., "Quantitative identification of emissions from abused prismatic Ni-rich lithium-ion batteries", eTransportation 2 (2019).
5: L. Mellert et al., "Elektromobilität und Tunnelsi-cherheit – Gefährdungen durch Elektrofahrzeugbrände", June 2018.
6: Y. Fernandes, A. Bry, and S. de Persis, Identification and quantification of gases emitted during abuse tests by overcharge of a commercial Li-ion battery, J. Power Sources 389 (2018) 106-119.
7: D. Sturk et al., Analysis of Li-Ion Battery Gases Vented in an Inert Atmosphere Thermal Test Chamber, Batteries 2019, 5, 61.
8: Willstrand et al., Toxic Gases from Fire in Electric Vehicles, RISE Report 2020:90 (2020).
9: Huang et al., Experimental investigation on thermal runaway propagation of large format lithium-ion battery modules with two cathodes, Int. J. of Heat and Mass Transfer 172 (2021) 121077.
10: DNV-GL, Considerations for ESS Fire Safety, Final Report prepared for Consolidated Edison and NYSERDA, New York, NY. February 9th 2017.
11: G.G. Eshetu et al. Fire behavior of carbonates-based electrolytes used in Li-ion rechargeable batteries with a focus on the role of the LiPF6 and LiFSI salts, Journal of Power Sources 269 (2014)
12: Golubkov et al. Thermal-runaway experiments on consumer Li-ion batteries with metal-oxide and olivin-type cathodes, RSC Adv., 4 (2014)
13: DNV-GL, Technical Reference for Li-ion Battery Explosion Risk and Fire Suppression. Report No. 2019-1025, Rev. 4

Table 3-3: A summary of the methods and conditions used in the experimental studies in quantifying emissions from battery fires

Study	Cell Type	Type of Abuse	SOC [%]	Duration of Emissions	Ignition	Atmosphere	Notes
1	Unspecified "pouch type"	Thermal (Fire)	0-100	~1-10 min	Yes	Ambient	Cell level tests.
2	LFP, unspecified laptop battery	Thermal (Fire)	0-100 (mostly 100)	~15-30 min	Yes	Ambient	Tests conducted on multiple cells in close proximity or mechanically fastened together; laptop battery packs including multiple cells, electrical connectors, electronic circuits and plastic housing.
3	LCO, LFP, NCA-LATP, 18650	Thermal (Fire)	0-100	~30 min	Yes	Ambient	Tests conducted on multiple cells not electrically connected to each other and a laptop battery pack including the plastic box, electronics and cables.
4	NMC	Thermal (External heating)	100	>14 min	No	Inert (N_2)	Cell level tests.
5	NMC	Physical (Mechanical: piercing; blunt force; high velocity projectile); & Thermal (Fire)	100	16-26 min	Yes	Ambient	Module (8 cells) level tests with the total mass of approximately 29 kg. Experiment carried out in large tunnel, with sampling point far from fire. Potential deposition/drop-out.
6	LFP	Electrical (Overcharge – charge cell beyond its limit)	135	6.25 hr	Unknown	Ambient	Cell level tests. Emissions of certain compounds (e.g., HF) were still present at end of test.
7	LFP, NMC/LMO	Thermal (Heating)	100	~45 min (LFP), ~4.5 min (NMC/LMO)	No	Inert (N_2)	Tests conducted on multiple cells clamped together.
8	NMC/LMO	Thermal (Fire)	~80	5-30 min	Yes	Ambient	Battery pack, module and cell level tests. Information on the battery mass tested not provided to derive with confidence emission factors per battery mass basis. The study also quantified emissions from battery car fire tests which included contribution from other car components. Emission factors from these tests were not considered and quantified for the purpose of this assessment.
9	LFP, NMC	Thermal (External heating)	100	30-60 min	Yes	Ambient	Module level tests (4 cells) with no electrical connection between cells.
10	NCM/LFP/ BM-LMP	Thermal (Heating) Electrical (Overcharge)	25-100	~13-83 min; Average ~42 min	Some cells self-ignited	Ambient	Cell level tests. Module level tests also conducted, but emissions not quantified.
11	No battery testing. Tests involved burning of LiPF6 or LiFSI-based carbonate electrolytes	Thermal (Heat flux using infrared heaters)	N.A.	Up to ~15 min	Yes	Ambient	Fire behavior of LiPF6 and LiFSI-based electrolytes was studied.
12	LCO/NMC, NMC, LFP	Thermal (External heating)	Battery at Cutoff Voltage	Test duration up to ~2 hours; Gas venting events a fraction of the time	No	Inert (Ar)	Cell level tests.
13	NMC, LFP	Thermal (External heating), Electrical (Overcharge), External short circuit	50-100, Overcharge, and External Short Circuit	~20-35 min	Yes	Ambient	Cell level tests.

As seen in **Table 3-2** and **Table 3-3**, the majority of the studies involved testing of Lithium Nickel Manganese Cobalt Oxide (NMC), Lithium Iron Phosphate (LFP), and Lithium Nickel Cobalt Aluminum Oxide ($LiNiCoAlO_2$ - NCA) batteries. Most of the investigations involved bench-scale experiments that evaluated the battery fire dynamics and products on a small scale and by testing individual battery cells. The mass of the battery cells used in those experiments typically varied between less than 100 grams to up to about 2 kilograms. Study #10 suggests the largest cells considered were approximately 6 kilograms. The largest battery energy capacities were evaluated in Studies #5 and #8, which were conducted using a 4,150 Wh (29 kg) battery module and up to a 8,400 Wh (~70 kg, estimated) battery pack, respectively. Study #10 (which does not include specifics on the testing parameters) appears to have been conducted on a number of individual battery cells of different sizes, capacities and types; the cells that were considered include those with masses in the range of approximately 0.5 kg to 6 kg.

As seen in **Table 3-3**, the majority of the studies conducted battery stress experiments in ambient air conditions, while two studies (#4 and #7) used nitrogen to prevent the ignition and allow quantification of the vented gases. These conditions would affect the chemistry and propagation of the ongoing combustion process. Most of the experimental measurements were limited to less than an hour (from several minutes to 45 minutes) except for Study #6 where monitoring lasted more than 6 hours. In the majority of studies, the experiments concluded after the burning process diminished, which suggests that the reported mass of contaminants accounts for the bulk of the release associated with the event. There is at least one study, study #6, whose data show that certain contaminants (in particular HF) continued being released after the completion of the experiment more than 6 hours after the start of the event. In addition, the majority of the studies involving individual cells observed that peak emission rates occur early in the combustion process, which suggests contaminant levels and associated risks would be lower during later stages of a fire. Studies that involved testing of the larger systems (modules, racks) typically quantified and reported total (cumulative) emissions. The data from these studies cannot be used to make direct inferences on the duration and dynamics of emission releases in a scenario where a fire involves a larger battery system, such as multiple racks in an enclosure. In such cases, emission intensity and duration would depend on the capacity of the battery system (total mass), the rate at which thermal runaway and fire propagate between individual cells, modules and racks, and a number of other factors such as fire characteristics (temperature, spatial extent, oxygen availability) which could vary over the lifetime of the fire.

The majority of tests reported in the reviewed studies did not involve active suppression methods and instead measured emissions as battery thermal runaway ran its course. However, the use of inert gas instead of air in Studies #4, #7, and #12, which were focused on testing the composition of the of vented gas rather than testing (fully) combusted thermal runaway products, would to an extent have suppressed the combustion reaction. While most of the studies measured the mass of gaseous products, Studies #4 and #5 also quantified particulate matter emissions. That data provides some insight into the speciation of particulate matter produced in the fires; however, there is considerable uncertainty in the reported particulate mass due to the experimental methods used and/or not accounting for particle deposition.

While the presence of **HCl** in battery fires is commonly reported, it was measured at detectable levels only in Studies #1, #9, and #10. Study #1 suggests that in general, the potential sources of chlorine would be polymers that may be found in three battery components: binder, separator, and packaging. Without providing specifics on the type of LiB used in the experiment, the study experiment established that the separator was the sole source of HCl. Study #4 quantified nearly 30 gaseous products and the reported HCl concentrations were below the method detection limit. Study #10, which reports an average emission rate for a large number of (different) battery cells, suggests that the measured HCl emissions are the result of the external plastics (PVC) burning "in the aftermath of thermal runaway."

HCN is another species of interest reported as a potential gaseous byproduct in battery fires. While Study #1 indicated that their Fourier Transform Infra-Red (FTIR) method was capable of monitoring HCN, no HCN was reported. The only two references that quantified HCN are Studies #10 and #11, with Study #10 suggesting that HCN is the byproduct of plastics burning.

In terms of quantified emissions, several studies reported emissions factors in the form of milligrams per watt-hour (mg/Wh) or milligrams per kilograms of battery (mg/kg). This is consistent with EPA's general approach to emissions factors.[109] For the remaining studies, with the exception of Study #10, Ramboll derived emissions factors on a mg/kg basis, using the data provided in the studies. Study #10 reported the emissions rates in their original format, as average emission rates in kg/s for the duration of the event which was estimated to last 30 minutes. The cells considered in the study ranged between approximately 0.5 kg and 6.5 kg. Emissions factors were derived conservatively by assuming the reported average emission rate is associated with the burning of the smallest cell considered in the study (0.5 kg) with the lowest mass. Using this approach produces the maximum emissions factors in mg/kg from the data reported. Because of this conservative methodology, the actual emissions factors may be substantially lower than the estimated emissions factors derived from this study.

As can be seen in **Table 3-2** and **Table 3-3**, there is a large variation in the magnitude of emissions factors on a per mass basis between the different studies. This may be the result of variations in testing, including the various type of batteries and chemistries tested and the inherent differences between the methodologies used to induce thermal runaway and quantify emissions. The majority of the studies involved cell level tests, with individual cell mass ranging between approximately 40 grams and 6.5 kilograms. Among the tests that quantified emissions from multiple cell thermal runaways,[110] the majority involved bundles of cells which were not electrically connected to each other. Emissions from integrated cells (in a pack or modules) undergoing thermal runaway were evaluated only in Studies #2, #3, #5, and #8.

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[109] EPA describes an emissions factor as "a representative value that attempts to relate the quantity of a pollutant released to the atmosphere with an activity associated with the release of that pollutant. These factors are usually expressed as the weight of pollutant divided by a unit weight, volume, distance, or duration of the activity emitting the pollutant (e.g., kilograms of particulate emitted per megagram of coal burned). Such factors facilitate estimation of emissions from various sources of air pollution." At https://www.epa.gov/air-emissions-factors-and-quantification/basic-information-air-emissions-factors-and-quantification. For example, the emissions factor (EF) for HF, which is expressed in terms of mg HF/kg battery (mg of HF released per 1 kg of battery burnt), is used in combination with the total mass of battery burnt to estimate total mass of HF released from such event as follows: Total mass of battery burnt [kg] x EF [mg HF/kg battery] = X mg HF released.

[110] These include Studies #2, #3, #5, #7, #8, and #9,although Studies #3 and #8 did not provide sufficient data to derive emission factors on a per mass basis.

Although some studies (beyond these reviewed) have suggested that the gaseous emissions from thermal runaway events may be proportional to the battery energy capacity,[111] this is not observed when comparing data from within this highly heterogeneous dataset (Study #1 through Study #13). The large variance in emissions factors from the studies shown in **Table 3-2** suggests that emissions are not simply proportional to the battery energy capacity.[112] This can also be seen in a meta-analysis[113] that included a comprehensive summary of all reviewed data.[114] Although the emissions factors were derived using two different bases (per battery mass or energy capacity) exhibit a similar degree of variation, emissions factors per unit mass were selected since there is a more fundamental link between the battery mass lost and the combustion products.[115]

Based on the relative magnitude of emissions factors and relevant air quality limits, and consistent with previous OCA reports for BESS facilities, the following contaminants had specific emissions factors derived for further analysis: HF, HCl, HCN and CO. **Table 3-4** summarizes the selected emissions factors used for emission estimates as part of this OCA. Emissions factors were derived on a mg/kg of battery basis. To provide a conservative estimate of impacts, the emissions factors in **Table 3-4** reflect the maximum emissions factors identified in the studies summarized in **Table 3-3**.

Table 3-4: Selected emission factors

Species	Emission Factor [mg/kg of battery]	Basis
HF	11,320	Study #2. Maximum of all studies reviewed with enough data to derive mg/kg emission factor.
HCl	2,575	Study #9. Maximum of all studies reviewed with enough data to derive mg/kg emission factor.
HCN	1,253	Study #10. Maximum of all studies reviewed with enough data to derive mg/kg emission factor. The study involved testing of batteries of different masses and capacities and reports a representative (or average) emission rate (in g/s). To convert this rate to mass basis, emission factor was derived assuming the smallest battery cell mass considered in the study (0.5 kg). This approach produces the most conservative (maximum) emission factor in mg/kg.
CO	46,228	Study #11. Maximum of all studies reviewed with enough data to derive mg/kg emission factor.

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[111] Koch (2018) Comprehensive gas analysis on large scale automotive lithium-ion cells in thermal runaway.pdf

[112] Variation in emission factors per Wh basis for studies in Table 3-2 for which such estimates could be derived. For example, HF emissions factors in mg/Wh between the studies vary by a factor of over 1,000.

[113] Rappsilber, T., Yusfi, N., Krüger, S., Hahn, S.-K., Fellinger, T.P., von Nidda, J. K., and Tschirschwitz, R. (2023) *Meta-analysis of heat release and smoke gas emission during thermal runaway of lithium-ion batteries.* Journal of Energy Storage, Volume 60.

[114] This meta-analysis reviewed 76 research papers from 2000 to 2021 studying potential emissions from battery thermal runaway events. Based on Ramboll's review of the supplemental data files, we believe some of the data may incorporate the author's assumptions, which raises uncertainties with the meta-analysis results.

[115] Electrolyte, separator, electrodes, binder, casing, etc. Note that total mass of airborne emissions associated with a burning battery are higher than the total battery mass loss because oxygen and nitrogen from air are incorporated in various thermal decomposition and combustion products.

3.3 Toxicological Consideration of Potential Air Releases

Based upon our review of the information concerning the dynamics of LiB fires, the results of experimental studies, and accidental fire reports (including reports indicating that the exposures from such incidents would be short-term), fires in large battery installations such as a BESS can last anywhere between under an hour and as long as several days. As discussed in Section 4.3, for the purpose of this analysis it was assumed that the event lasts for 24 hours. The estimated concentrations that result from the release should therefore be evaluated against the limits that are available and applicable to that period. These include 60-minutes, 30 minutes, 10 minutes, and 8-hour exposure limits.

For the purposes of this evaluation, we are using either the AEGL-2 or the ERPG-2. We chose the lower of the two as the threshold of concern to maintain a conservative approach. Both AEGL-2 and ERPG-2 are intended to identify levels of airborne emissions that could cause irreversible or other serious, long-lasting adverse health effects. This is typical for OCAs, as reversible impacts such as temporary coughing and watery eyes resolve soon after exposures. The AEGL and ERPG exposure limits are shown in **Table 3-5**. The acute health effects associated with short-term (from a few minutes to a few hours) exposure to these four chemicals can be found in **Table 3-6** below.

Table 3-5: Exposure limits

	Hydrogen Fluoride (HF)	**Hydrogen Chloride (HCl)**	**Hydrogen Cyanide (HCN)**	**Carbon Monoxide (CO)**
CAS	7664-39-3	7647-01-0	74-90-8	630-08-0
	8 hour	**8 hour**	**8 hour**	**8 hour**
AEGL-1 (ppm)	1.0	1.8	1.0	NR
AEGL-2 (ppm)	12	11	2.5	27
AEGL-3 (ppm)	22	26	6.6	130
	60 min	**60 min**	**60 min**	**60 min**
AEGL-1 (ppm)	1	1.8	2	NR
AEGL-2 (ppm)	24	22	7.1	83
AEGL-3 (ppm)	44	100	15	330
ERPG-1 (ppm)	2	3	NA	200
ERPG-2 (ppm)	20	20	10	350
ERPG-3 (ppm)	50	150	25	500
	30 min	**30 min**	**30 min**	**30 min**
AEGL-1 (ppm)	1	1.8	2.5	NR
AEGL-2 (ppm)	34	43	10	150
AEGL-3 (ppm)	62	210	21	600
	10 min	**10 min**	**10 min**	**10 min**
AEGL-1 (ppm)	1	1.8	2.5	NR
AEGL-2 (ppm)	95	100	17	420
AEGL-3 (ppm)	170	620	27	1700
NR – Not recommended due to insufficient data NA – Not appropriate				

[a] US EPA. Access Acute Exposure Guideline Levels (AEGLs) Values. https://www.epa.gov/aegl/access-acute-exposure-guideline-levels-aegls-values

[b] CAMEO Chemicals. https://cameochemicals.noaa.gov/search/simple

Table 3-6: Description of potential health effects

	Description	Acute (short-term) inhalation effects for relevant thresholds[116]
Hydrogen fluoride[117]	HF is a colorless, highly irritating, corrosive gas. HF is highly soluble in water with the ability to react quickly, producing heat and hydrofluoric acid, which has a strong odor and is one of the strongest acids known.	Includes irritation of the eyes, nose, upper and lower respiratory tract. Tearing of the eyes, sore throat, cough, chest tightness, and wheezing have also been reported.
Hydrogen chloride[118]	HCl is a colorless, nonflammable aqueous solution or gas. It has an irritating, pungent odor. HCl is corrosive to the eyes, skin, and mucous membranes.	Includes coughing and hoarseness. Exposure at higher concentrations can cause inflammation and ulceration of the respiratory tract, chest pain, and pulmonary edema.
Hydrogen cyanide[119]	HCN is a colorless gas or liquid with a faint, bitter almond odor.	Includes weakness, headaches, nausea, increased rate of respiration, and eye and skin irritation.
Carbon monoxide	CO is a colorless, odorless gas. It is extremely toxic and flammable. Exposure to CO can occur via inhalation, skin contact, and eye contact.[120]	Includes headache, nausea, rapid breathing, weakness, exhaustion, and dizziness.[121]

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[116] This table addresses potential acute health effects at concentrations at or below AEGL-2 and ERPG-2. Additional information is available in the cited references.

[117] USEPA. Health Effects Notebook for Hazardous Air Pollutants. https://www.epa.gov/sites/default/files/2016-10/documents/hydrogen-fluoride.pdf accessed on March 9, 2024.

[118] USEPA. Health Effects Notebook for Hazardous Air Pollutants. https://www.epa.gov/sites/default/files/2016-09/documents/hydrochloric-acid.pdf accessed on March 9, 2024.

[119] USEPA. Health Effects Notebook for Hazardous Air Pollutants. https://www.epa.gov/sites/default/files/2016-09/documents/hydrochloric-acid.pdf accessed on March 9, 2024.

[120] Centers for Disease Control and Prevention. The National Institute for Occupational Safety and Health (NIOSH). https://www.cdc.gov/niosh/npg/npgd0105.html. Accessed on March 20, 2023.

[121] Centers for Disease Control and Prevention. The National Institute for Occupational Safety and Health (NIOSH). https://www.cdc.gov/niosh/topics/co-comp/. Accessed on March 20, 2023

4. OFFSITE CONSEQUENCE ANALYSIS

4.1 Introduction

Vistra is voluntarily preparing this OCA to inform decision-makers and the public regarding the impacts of a potential battery fire. Typically, OCAs are conducted as a part of the Risk Management Program required under the Clean Air Act[122] for facilities that store, handle, use, and manufacture quantities of hazardous materials above the limits outlined in 40 CFR 68.130.[123] Those requirements do not apply to the BESS facility because it will not store, handle, use, or manufacture quantities of hazardous materials above the threshold limits. This OCA is instead being prepared to inform the public by identifying and evaluating the maximum and reasonably expected impacts of a potential battery fire.

An OCA is intended to provide information "about the potential consequence of an accidental chemical release."[124] OCAs typically evaluate two scenarios, a worst-case release scenario and an alternative release scenario. A worst-case scenario is typically one where the largest quantity of a regulated substance is released from a single vessel or process line during a failure (a maximum credible event) and the meteorology maximizes the impacts of that maximum credible event. Alternative release scenarios are the more realistic scenarios that are more likely to occur both as to the quantity of material released and as to the meteorological conditions considered. If the worst-case scenario does not result in an exceedance of applicable thresholds, then there is no need to model an alternative scenario evaluation as any such scenario would necessarily not result in an exceedance. In this case, the worst-case scenarios for both the Proposed Project and Enclosure Alternative did not result in an exceedance of AEGL-2 and ERPG-2 thresholds. Therefore, additional scenarios were not analyzed in this OCA.

The OCA identifies the endpoint or furthest distance where serious injuries from short-term exposures would no longer occur. A list of parameters for the worst-case and alternative release scenarios is provided in the US EPA Risk Management Program Guidance for Offsite Consequence Analysis document in Exhibit 1.[125] However, because these scenarios are for chemical releases and not for fires that release products of combustion, this guidance must be applied in context. An OCA analysis requires estimates and inputs for emission source parameters such as the release height above ground, lateral dimensions or surface area, temperature, meteorological conditions at which end-point distances are estimated, and others. The RMP Guidance prescribes certain input parameters and assumptions for the worst-case and alternative scenarios[126] while other input parameters are source- and site-specific.[127] Because there is no guidance specifically prescribed for this analysis, the selection of the dispersion model and modeling inputs are made in accordance with California guidance (i.e., CalARP), the EPA's RMP Guidance for Offsite

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[123] National Archives. 68.130 List of substances. https://www.ecfr.gov/current/title-40/chapter-I/subchapter-C/part-68/subpart-F/section-68.130 accessed on January 20, 2023

[124] USEPA (2009). Risk management program guidance for offsite consequence analysis. Available at: https://www.epa.gov/sites/default/files/2013-11/documents/oca-chps.pdf

[125] Ibid

[126] For example, meteorological parameters such as wind speed and atmospheric stability to be used for the two scenarios or that source elevation for the worst-case scenario should be set to 0 m regardless of its actual elevation above ground.

[127] For example, the type of source representation of the release, maximum ambient temperature, or in case of alternative scenarios for which source parameters can be based on more realistic estimates.

Consequence Analysis, and other general dispersion modeling guidance developed by the US EPA and CARB to ensure that a conservative analysis is being conducted.

The rationale for the selection of the dispersion model and the inputs for the Offsite Consequence Analysis are explained below.

4.2 Selection of Dispersion Models Used for Offsite Consequence Analysis

There are several options for models that can be used to estimate offsite consequences for fires and other release scenarios. These range from simple models used by first responders, such as the Areal Locations of Hazardous Atmospheres (ALOHA) atmospheric dispersion model maintained by the National Oceanic and Atmospheric Administration (NOAA) Office of Response and Restoration’s Emergency Response Division, to more complex proprietary models such as PHAST.[128] There are also intermediate models lying between the very complex models and the very simplistic models, including SCREEN3 and AERSCREEN.

ALOHA is used primarily to evaluate the consequences of atmospheric releases of chemical species.[129] ALOHA allows the user to estimate the downwind dispersion of a chemical cloud based on the toxicological and physical characteristics of the released chemical, atmospheric conditions, and specific circumstances of the release. ALOHA was originally intended to model simple spills and releases, but was upgraded in 2006 to model the hazards associated with fires and explosions, specifically, the hazards associated with jet fires (flares), pool fires, vapor cloud explosions (VCE), BLEVEs (Boiling Liquid Expanding Vapor Explosions), and flammable regions (flash fires).[130] Unfortunately, none of the fire and explosion scenarios effectively fit the characteristics of a battery fire.

PHAST is a proprietary model owned by DNV Technica. PHAST models the discharge, dispersion, fires, explosions, and toxic effects of a wide range of loss of containment scenarios, but does not have a module associated with battery fires. However, DNV stated that the plume model incorporated into PHAST could be used to model battery fires.[131]

SCREEN3 is a screening version of the Industrial Source Complex, version 3 (ISC3) model. This US EPA-approved[132] air dispersion model is used to analyze single source release scenarios over simple or complex terrain. The model can predict downwind short-term (1-hr average) exposure for a single source for a range of wind speeds and stability classes. While there is no mapping provided, this simple model is useful for estimating the impacts of releases under a variety of conditions.

AERSCREEN is the recommended screening model. It is based on AERMOD, the latest USEPA steady-state air dispersion plume model. AERMOD includes the treatment of both surface and elevated sources, and both simple and complex terrain. AERSCREEN produces estimates of “worst-case” 1-hour concentrations for a single source, without the need for hourly meteorological data, and also includes conversion factors to estimate “worst-case” 3-hour, 8-

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[128] PHAST Model. https://www.dnv.com/software/services/plant/consequence-analysis-phast.html

[129] U.S Department of Energy. ALOHA. www.energy.gov/ehss/aloha

[130] Ibid.

[131] DNV GL. (2017) Considerations for ESS Fire Safety for Consolidated Edison and NYSERDA.

[132] USEPA (1995). SCREEN3 Model User’s Guide, September. https://gaftp.epa.gov/Air/aqmg/SCRAM/models/screening/screen3/screen3d.pdf

hour, and 24-hour concentrations. AERSCREEN is intended to produce concentration estimates that are equal to or greater than the estimates produced by AERMOD with a fully developed set of meteorological and terrain data. While AERSCREEN can consider some site-specific inputs such as temperature range, surface characteristics, or relative building and stack layout, the screening meteorological data utilized by AERSCREEN represent a conservative matrix (combination) of meteorological and surface parameters including those that are not likely to occur at the same time. In addition, the maximum concentrations predicted by AERSCREEN and the distances of the maximum concentrations from the source are interpreted conservatively, as equally likely to occur in any wind direction. As a result, the predicted distances from a source at which concentrations drop below applicable exposure limits are presented as the diameter of a circle around the source. AERSCREEN is designed to model only 1-hour concentrations. Concentrations for longer time periods such as 3-hr, 8-hr, and 24-hr are estimated from modeled 1-hr concentration and screening conversion factors, another layer of conservatism associated with using AERSCREEN and screening models in general.

A fire will result in an elevated plume with some heat associated with it. ALOHA is not designed to handle fires outside of the specific scenarios contained in the program, which does not include battery fires. PHAST does not have a battery fire module and, as a proprietary model, is less appropriate for use in a public-facing evaluation. SCREEN3 and AERSCREEN can both be appropriate for use in this analysis, but AERSCREEN is more recent and is being continually updated. Accordingly, we are using AERSCREEN for this analysis.

4.3 Modeled Emission Rates

The emissions factors for HF, HCl, HCN, and CO used in this analysis are presented as milligrams per kg of battery, as set forth in **Table 3-4**. As described in Section 3 of this report, these emission factors represent a conservative interpretation of the literature on emissions from the combustion of batteries. These emissions factors can be used to derive emission rates (g/s), based on the assumed mass of batteries experiencing a thermal event and the duration over which the emissions will occur. Our review of the historic BESS incidents involving LiB shows that such fires can last from about 30 minutes to several hours, and in limited situations, combustion and off-gassing has lasted days. For this assessment, for both the Proposed Project and the Enclosure Alternative, it was assumed that the emissions from maximum credible fire event due to thermal runaway would occur over a 24-hour period.

As set forth in Section 1.2 and depicted in Figure 1-4, battery modules in the Proposed Project layout are closely packed in racks (25 modules per rack), which are further grouped in blocks (approximately 48 racks per block) within the buildings. This totals approximately 1,200 modules per block. Each block would be separated by thermal- and fire-resistant barriers and equipped with its own fire protection and safety system. In case of spontaneous thermal runaway in a module, thermal runaway and fire would tend to first spread to other modules in the rack due to their close contact. And although each battery module and rack has casings that provide some degree of protection and separation from other modules and racks, the thermal runaway could spread to adjacent modules and racks with sufficient time, and thermal runaway in one rack could propagate further to other nearby racks. Given that blocks are designed to be insulated units (groups of racks) with fire resistant barriers and protection and with sufficient separation from other blocks to prevent propagation, it is not expected that thermal runaway would propagate beyond an individual block. We note the modeled fire event conservatively assumes that all active measures fail, including continuous monitoring and safety systems designed to prevent a spontaneously initiated runaway event (and fire) from advancing to other modules and racks. For the Proposed Project, we assume the maximum credible fire event involves combustion of an entire block of batteries during a 24-hour period.

For the Enclosure Alternative scenario, we conservatively assume that the maximum credible fire event involves combustion of the entire contents of one enclosure. This is based on the assumption that the fire would be contained within a single enclosure due to the exterior thermal and noncombustible casing of each enclosure and the physical spacing between enclosures, which also enables responders to access and localize the fire. As above, we note this analysis conservatively assumes that all active measures fail. As set forth in Section 1.2, this scenario corresponds to 46 battery strings (racks). This is nearly 2 racks (approximately 4,215 kg of battery material) combusted per hour.

Because both the Proposed Project and the Enclosure Alternative scenarios represent the combustion of approximately the same battery mass at the site, the emissions scenarios are equivalent and were modeled assuming the same mass of the battery (101,200 kg) burning over the same period (24-hours).

The assumption of a continual combustion over 24 hours represents a significant increase in the combustion event compared to most previously studied events. A more typical BESS fire incident would be expected to burn out (via spacing and thermal noncombustible barriers) or be suppressed (by the fire system or emergency responders) before the fire consumes this quantity of batteries.

Table 4-1 presents 1-hour emission rates estimated for the maximum credible event emissions rates for BESS fire scenarios.

Table 4-1: Modeled 1-hour release rates per battery module and corresponding emission factors for both the Proposed Project and Enclosure Alternative scenarios

Species	Modeled Emission Rates (g/hr)
HCN	5,283
HF	47,733
CO	10,858
HCl	194,937

4.4 Selection of Source Parameters for Dispersion Modeling

The impact of a release is dependent on the emission release height above ground, source lateral dimensions (e.g., width or area), vertical spread (in certain instances), release temperature of emissions, exit velocity of emissions, height of the release (when applicable), and the heat generated in the release. These are referred to as "source parameters" for modeling purposes.

This section includes a brief overview of how emissions from BESS facilities typically behave and what type of fire scenarios would represent the conservative parameters from a modeling perspective. The behavior of emissions from BESS fires can be inferred by considering information including:

- Plume behavior observed during past BESS fires based on images, videos and other descriptions;[133]
- Basic physical phenomena governing the behavior of fires and resulting plumes;
- Site-specific information such as the layout and dimensions of the project structures,[134] and building openings; and
- Basic dispersion and source parameterization principles to identify conservative source representation.

This section sets forth the relevant source parameters for dispersion modeling, including release height, lateral dimension, temperature, and velocity of emission. It explains the selection of the conservative assumptions made for each parameter and identifies where the parameter differs between the Proposed Project and the Enclosure Alternative.

4.4.1 Release Height

In general, due to the tendency of hot gases to move upwards (the buoyancy effect) emissions from battery fires tend to escape from the structure through openings and vents in the upper parts of the building structure. Typical behavior of plumes from BESS fires observed and documented in the past (accidental fires or controlled fire tests) may be grouped in two main categories:

(i) Fumes are released into the ambient air near the building top such as though vents and openings at or near the rooftop or through breached sections of the roof. In this scenario the physical emission release height would approximately correspond to the height of the structure (e.g. building or enclosure).

(ii) In cases when there is a breach in the structure's outside doors and walls, the plume (emissions) can exit the structure horizontally. Even in such instances, upon exiting the structure the plume quickly starts to move upwards (and in the general direction of wind) due to buoyancy. In this scenario, when the plume leaves the building horizontally, the physical height of the emission release (the centerline of the release) would be approximately at the height of the opening through which smoke escapes.

In general, the higher the height of the release, the lower the concentrations at or near the ground level where most human exposure occurs.

4.4.2 Release Lateral Extent

Depending on the intensity of the fire, the release point, potential breach of structure, and other relevant factors, the lateral size (width) of an emission plume leaving the building can be:

a) Confined to a narrow segment of the building (e.g. width of a vent, door, isolated section of the building immediately affected by fire).

b) As large as the dimension of the structure's dimensions (e.g. in an unlikely scenario where the entire structure or rooftop area is engulfed in flames generating fumes).

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[133] This assessment is focused on modeling dispersion of gaseous toxic compounds released during a potential BESS fire.

[134] The proposed project buildings are 260ft x 350ft and 30 ft high.

A simple example of a lateral dimension of a source would be a vent diameter at the point where the plume exits the structure. In cases when the opening is not circular, the area is converted to an equivalent diameter.

4.4.3 Release Temperature

The LiB thermal runaway onset temperatures typically range between 200°C and 300°C, which (if unchecked) can be followed by additional temperature increases from thermal runaway of approximately 120°C to 550°C above the initial onset temperature, potentially resulting in cell temperatures between 350°C and 750°C (or even higher). The temperature of the emission release will depend on many factors including type of batteries, the extent and stage of fire, building ventilation, air entrainment, thermal losses, and many others. From a dispersion modeling perspective, the most conservative scenario would assume a source with minimum temperature and buoyancy, thereby resulting in lower plume rise.[135]

4.4.4 Release Exit Velocity

The exit velocity of an emissions release (velocity at which it exits openings on the rooftop or side walls) is driven by a number of factors such as the specific characteristics of batteries and the thermal runaway event, including the volume of solvents released, rate of volatilization and expansion of gases with increasing temperatures; ventilation arrangements in the building; the size of the opening through which releases escape; and other factors. The velocity of the plume exiting the building has a similar effect as buoyancy where the higher plume velocity (and resulting mass momentum) leads to more efficient mixing and dilution with air. From a dispersion modeling perspective, assuming lower exit velocity would typically produce less air entrainment by the plume, resulting in higher predicted concentrations.

4.5 Parameters Used for AERSCREEN Modeling

Receptor representation

A linear grid was used to represent the receptors in one-meter increments. The receptor height was assumed to be at breathing level, or 1.5 m to be conservative.

Source representation

Several types of source representations in AERSCREEN can be used to model emission releases from potential BESS fires. They include a point source, volume source, and area source. The point source representation in AERSCREEN can account for the effect of buoyancy, momentum, and building downwash on release dispersion. Accordingly, a point source will be used in this analysis. Parameters for the point source categories selected to produce the most conservative results are presented in **Table 4-2** and **Table 4-3** for the Proposed Project and Enclosure Alternative, respectively.

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[135] This is because higher emission release temperature results in higher plume rise (due to higher buoyancy) moving the plume further from breathing height level (assuming receptors near or at the ground). This process is also characterized by higher level of air entrainment resulting in more effective dilution of emission in part due to increasing wind speeds at higher elevations.

Table 4-2: Point source parameters modeled for the maximum credible event for the Proposed Project

Proposed Project		
Source Parameter	**Modeled Value**	**Rationale**
Release height above ground	3.0 m	Approximate height of a vent exhaust on the first-floor level of the two-story building.
Exit diameter	0.9 m	Assumed effective diameter of the air exhaust vent
Exit velocity	2.89 m/s	Exit velocity is estimated assuming that the total gas flow rate (air and by-product) is equivalent to the flow rate in the Enclosure Alternative. This is a conservative assumption given that ventilation rates are expected to be higher in larger structures.
Exit temperature	632 K (678°F)	Temperature of exhaust gases assumed to be lower that in the enclosure scenario due to the higher ventilation and heat loss potential in larger structures.
Stack location relative to building	At a building center	Conservative stack-to-building configuration
Stack orientation	Horizontal	Conservative stack orientation

Table 4-3: Point source parameters modeled for the maximum credible event for the Enclosure Alternative

Enclosure Alternative		
Source Parameter	**Modeled Value**	**Rationale**
Release height above ground	4.6 m	The release height is assumed to be at the enclosure height (rooftop height). Driven by buoyancy hot gases tend to rise and are expected to be initially discharged via an air exhaust vent following the path of least resistance. In one story structures such as enclosures, discharge vents are typically located near or at rooftop height.
Exit diameter	2.0 m	An air exhaust vent is assumed to be 0.9 m in diameter. The exit plume diameter is set to be larger than the assumed exhaust vent diameter (4 times larger area) to account for potential deterioration of rooftop structure during fire.
Exit velocity	0.87 m/s	The gas flow rate out of the enclosure is primarily due to combustion gases (by-products) and entrained air. Even if the mechanical ventilation system were to be damaged the discharge of hot combustion gases creates a negative pressure resulting in air entrainment (natural draft). Exit velocity is estimated assuming that the total gas flow (air and by-product) rate is equivalent to the flow corresponding to 10 air exchanges in the enclosure.
Exit temperature	900 K	Temperature represents a conservative (low) estimate based on the approximate heating value of the battery material burnt (electrolyte, separator, binder), total assumed gas flow rate and estimated thermal losses. The heat release rate associated with the burning of the entire enclosure in a 24-hour period is sufficient to produce temperatures considerably higher than 900 K.

Stack location relative to building	At a building center	It is expected that the exit point of the plume would initially depend on the location of the exhaust vents but will likely vary over the duration of the fire. A centrally located stack produces plumes strongly subject to downwash which lowers the effective plume centerline and moves it closer to the ground and receptor locations resulting in the most conservative results.
Stack orientation	Vertical	Conservative stack orientation.

Meteorological and surface parameters

The meteorological parameters for the worst-case scenario are selected consistent with the RMP guidance, which requires the use of wind speed of 1.5 m/s and an atmospheric stability of "class F," which is representative of the highly stable conditions corresponding to poor vertical mixing and dispersion.[136] The AERSCREEN model uses screening meteorological data that represent a matrix of meteorological conditions which include a range of stabilities and wind speed conditions including those representative of stability F at wind speed 1.5 m/s and lower. The screening meteorological dataset is generated using site-specific inputs such as the minimum and maximum hourly temperature, minimum wind speed and surface characteristics. We used meteorological parameters from the nearest observation points: San Luis Obispo Regional Airport and Oceano County stations. As noted, although the Oceano County site is located further from Morro Bay than San Luis Obispo, the site is more representative of the Morro Bay setting. Nonetheless, the worst-case analysis is carried out using data from both locations to estimate the temperature extremes (maximum and minimum 1-hour temperature) which are used to develop the matrix of the meteorological conditions. **Table 4-4** presents meteorological and surface characteristic inputs that were used to generate the screening meteorological dataset.

Table 4-4: Meteorological parameters and surface characteristics modeled in the analysis

Building and Enclosure Scenarios		
Source Parameter	**Modeled Value**	**Rationale**
Maximum temperature	320 K (116 °F)	Maximum temperature at two meteorological stations (conservative assumption)
Minimum temperature	270 K (26 °F)	Minimum temperature at two meteorological stations (conservative assumption)
Minimum wind speed	0.5 m/s[137]	Conservative assumption
Surface characteristics	Parameters varying by month and by wind sector	Site-specific surface parameters extracted using 2016 LULC data
Urban/rural designation	Rural	Conservative assumption

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[136] These meteorological conditions are conducive to poor dispersion and emission dilution. However for some other source configurations (e.g. elevated emission releases and/or those with high buoyancy or vertical momentum) these conditions may not lead to the worst-case concentrations and endpoint distances. The RMP guidance on the worst-case scenario is designed to employ the source representation in combination with meteorology parameters which would lead to the most conservative end-point predictions.

[137] This represents the minimum wind speed considered by the model, which is lower and more conservative than the 1.5 m/s required by the federal Risk Management Program. We modeled concentrations at a variety of wind speeds to ensure that the highest estimated concentration was captured in the assessment.

As seen in **Figure 4-1** the Project is located in an area that includes a mix of land uses and characteristics, from high- and medium-density uses (industrial and residential) to open spaces (parks) and open water. Due to the presence of industrial land uses, residential development, and complex terrain, the surface roughness would typically be characterized as urban. However due to the presence of open spaces and water in close proximity to the site, surface characteristics were determined by using 2016 Land Use data combined with the AERSURFACE processor to extract surface parameters including surface roughness lengths, albedo and Bowen ratios in each of the 12 30-degree sectors and how they vary by month. These parameters were used as one of the inputs to generate the screening meteorological file used in AERSCREEN modeling.

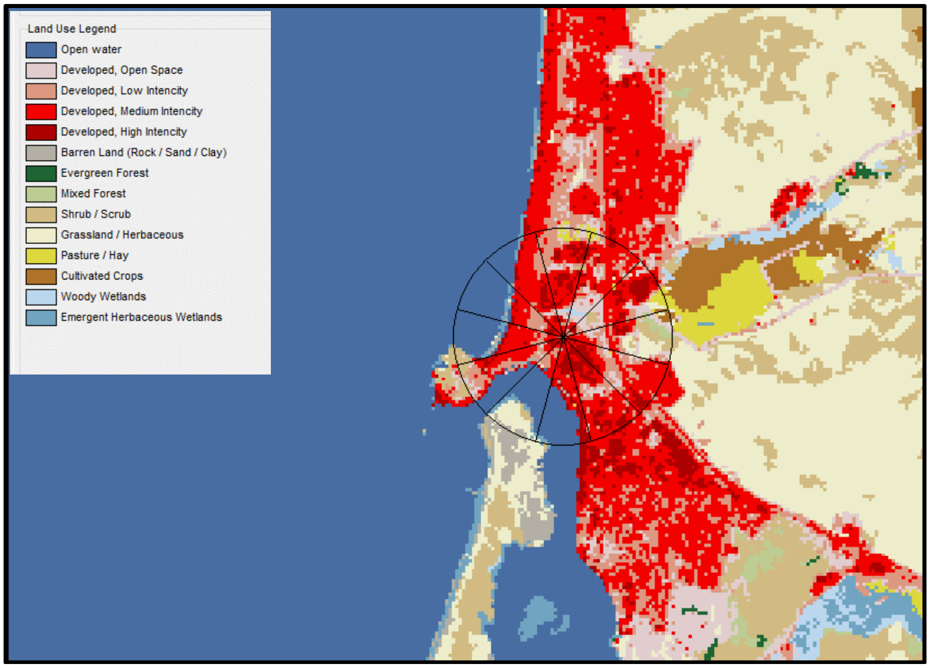

Figure 4-1: Land use within 1 km radius around the Project site

4.6 Results and Discussion

This OCA presents the estimates of the potential impacts of a maximum credible fire event on sensitive receptors located near the BESS Site under worst-case conditions. The worst-case estimated concentrations resulting from emissions from the Proposed Project and Enclosure Alternative scenarios are presented in **Table 4-5** through **Table 4-8**, along with color-coding showing that both scenarios result in concentrations below the standards for all chemicals for all averaging times. Cells shown in green are between zero and 50% of the standard, and cells shown in yellow are between 50% of the standard and 85% of the standard.

While both the Proposed Project scenario and the Enclosure Alternative scenario result in concentrations that are below the relevant standards, the Proposed Project scenario does result in a concentration notably closer to the 8-hour CO standard as compared to the Enclosure Alternative scenario, where all concentrations are well below the applicable standards. This OCA makes several assumptions designed to evaluate the worst-case impacts from a maximum credible fire event, including:

- The number of batteries that may be involved in the fire;
- The meteorological conditions during the fire; and
- The release parameters for the emissions from the fire.

Furthermore, while it is challenging to estimate the maximum likely combustion rate for the fire scenarios, as discussed above, it should be noted that the fire scenario for the enclosure assumes that the entire enclosure burns in 24 hours. The same rate is used for the building scenario.

Tables 4-5 to **Table 4-8** illustrates the concentrations of HCN, HF, HCl, and CO at the closest receptor, and the percentage of the relevant limit. A figure under 100% means that the estimated maximum concentrations are below the applicable threshold limit. The concentrations at the closest receptor are higher for the Proposed Project compared to the Enclosure Alternative, a difference that is likely because of the characteristic of the plume. For the Enclosure Alternative, the highest concentration occurs closest to the emission source, and the concentration gradually decreases as distance from the emission source increases. However, for the Proposed Project, the highest concentration occurs several meters away from the building footprint, and then decreases with distance. While the concentration at the nearest residence would not exceed the AEGL-2 or ERPG-2 limits, the concentrations at the closest receptor are predicted to be higher for the Proposed Project than the Enclosure Alternative due to these different concentration profiles between the two scenarios.

Table 4-5: Maximum modeled HCN concentrations at closest receptors

HCN	AEGL-2 8-hr	AEGL-2 60-min	ERPG-2 60-min	AEG-2 30-min	AEGL-2 10-min
Exposure Guideline (ppm)	2.5	7.1	10	10	17
Enclosure Alternative					
Concentration at the Closest Residence (ppm)	0.3	0.34	0.34	0.41	0.56
Concentrations at the Closest Residence as a Percentage of the Limit	12%	5%	3%	4%	3%
Proposed Project					
Concentration at the Closest Residence (ppm)	0.62	0.69	0.69	0.84	1.14
Concentrations at the Closest Residence as a Percentage of the Limit	25%	10%	7%	8%	7%

Table 4-6: Maximum modeled HF concentrations at closest receptors

HF	AEGL-2 8-hr	AEGL-2 60-min	ERPG-2 60-min	AEG-2 30-min	AEGL-2 10-min
Exposure Guideline (ppm)	12	24	20	34	95
Enclosure Alternative					
Concentration at the Closest Residence (ppm)	3.7	4.11	4.11	4.99	6.79
Concentrations at the Closest Residence as a Percentage of the Limit	31%	17%	21%	15%	7%
Proposed Project					
Concentration at the Closest Residence (ppm)	7.59	8.43	8.43	10.23	13.92
Concentrations at the Closest Residence as a Percentage of the Limit	63%	35%	42%	30%	15%

Table 4-7: Maximum modeled HCl concentrations at closest receptors

HCl	AEGL-2 8-hr	AEGL-2 60-min	ERPG-2 60-min	AEG-2 30-min	AEGL-2 10-min
Exposure Guideline (ppm)	11	22	20	43	100
Enclosure Alternative					
Concentration at the Closest Residence (ppm)	0.46	0.51	0.51	0.62	0.85
Concentrations at the Closest Residence as a Percentage of the Limit	4%	2%	3%	1%	1%
Proposed Project					
Concentration at the Closest Residence (ppm)	0.95	1.05	1.05	1.28	1.74
Concentrations at the Closest Residence as a Percentage of the Limit	9%	5%	5%	3%	2%

Table 4-8: Maximum modeled CO concentrations at closest receptors

CO	AEGL-2 8-hr	AEGL-2 60-min	ERPG-2 60-min	AEG-2 30-min	AEGL-2 10-min
Exposure Guideline (ppm)	27	83	350	150	420
Enclosure Alternative					
Concentration at the Closest Residence (ppm)	10.8	12	12	14.57	19.81
Concentrations at the Closest Residence as a Percentage of the Limit	40%	14%	3%	10%	5%
Proposed Project					
Concentration at the Closest Residence (ppm)	22.13	24.59	24.59	29.86	40.61
Concentrations at the Closest Residence as a Percentage of the Limit	82%	30%	7%	20%	10%

As is shown in **Table 4-5** through **Table 4-8**, the modeled concentrations under a maximum credible fire event for each of the relevant time periods—10 minutes, 30 minutes, 60 minutes and 8 hours—are all below the relevant health-protective thresholds. Cells shown in green are between zero and 50% of the standard, and cells shown in yellow are between 50% of the standard and 85% of the standard. For the Enclosure Alternative, the estimated impacts are considerably lower than the health protective thresholds. The maximum predicted concentration closest to the relevant threshold is the 8-hour AEGL for CO, where the estimated concentration is 40% of the threshold. For the Proposed Project, all estimated concentrations are below the health protective thresholds, but two estimated concentrations are above 50% of the health protective thresholds: 8-hour HF and 8-hour CO. These results are also shown graphically in **Figure 4-2** through **Figure 4-7**.

As noted, this OCA evaluates potential emissions during a maximum credible fire event where an entire block within a building (for the Proposed Project) or an entire enclosure (for the Enclosure Alternative) completely burns within 24 hours. This is a highly unlikely scenario based on the historical data and the safety measures that will be put in place. The OCA also presumes that the worst-case meteorology occurs during the event, and that the source parameters for the thermal result in the lowest dispersion. It also assumes that there is no evacuation of the nearest residents during the event and that residents are outside during the entire event rather than "sheltering in place." It also assumes that the winds are systematically blowing in the general direction of the nearest resident, which is unlikely based on the meteorology of the site.

Table 4-9 provides the distance where the concentration of each compound (HCN, HF, HCl, and CO) would fall below the applicable ERPG-2 or AEGL-2 threshold value. A cell without a value for distance indicates that the concentration of the compound never exceeded the applicable ERPG-2 or AEGL-2 limits. For example, the AEGL-2 8-hr limit of HF is 12 ppm. If the concentration of HF never exceeded 12 ppm, this would not result in a distance and the cell would show "-". If instead the HF concentration exceeded 12 ppm at a distance from 1-10 m from the emission source (which would be onsite) but is then reduced to below the limit at 11 m, this would result in an 11 m distance in the table.

Table 4-9: Predicted maximum toxic endpoint distance

Species	HCN	HF	HCl	CO	HCN	HF	HCl	CO	HCN	HF	HCl	CO	HCN	HF	HCl	CO
Exposure Duration	**60-min**				**30-min**				**10-min**				**8-hr**			
	Exposure Guideline															
AEGL (ppm)	7.1	24	22	83	10	34	43	150	17	95	100	420	2.5	12	11	27
ERPG (ppm)	10	20	20	350												
Modeled Scenario	**Predicted Maximum Toxic Endpoint Distance Above the Threshold (m)**															
Enclosure - AEGL	7	17	6	16	7	16	5	10	6	8	4	7	16	37	7	70
Enclosure – ERPG	7	19	6	7												
Building - AEGL	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	131
Building - ERPG	-	-	-	-												

Note: "-" means there is no concentration in excess of the identified guidelines.

Figure 4-2: AEGL 60-min – Enclosure Alternative

Figure 4-3: ERPG 60-min - Enclosure Alternative

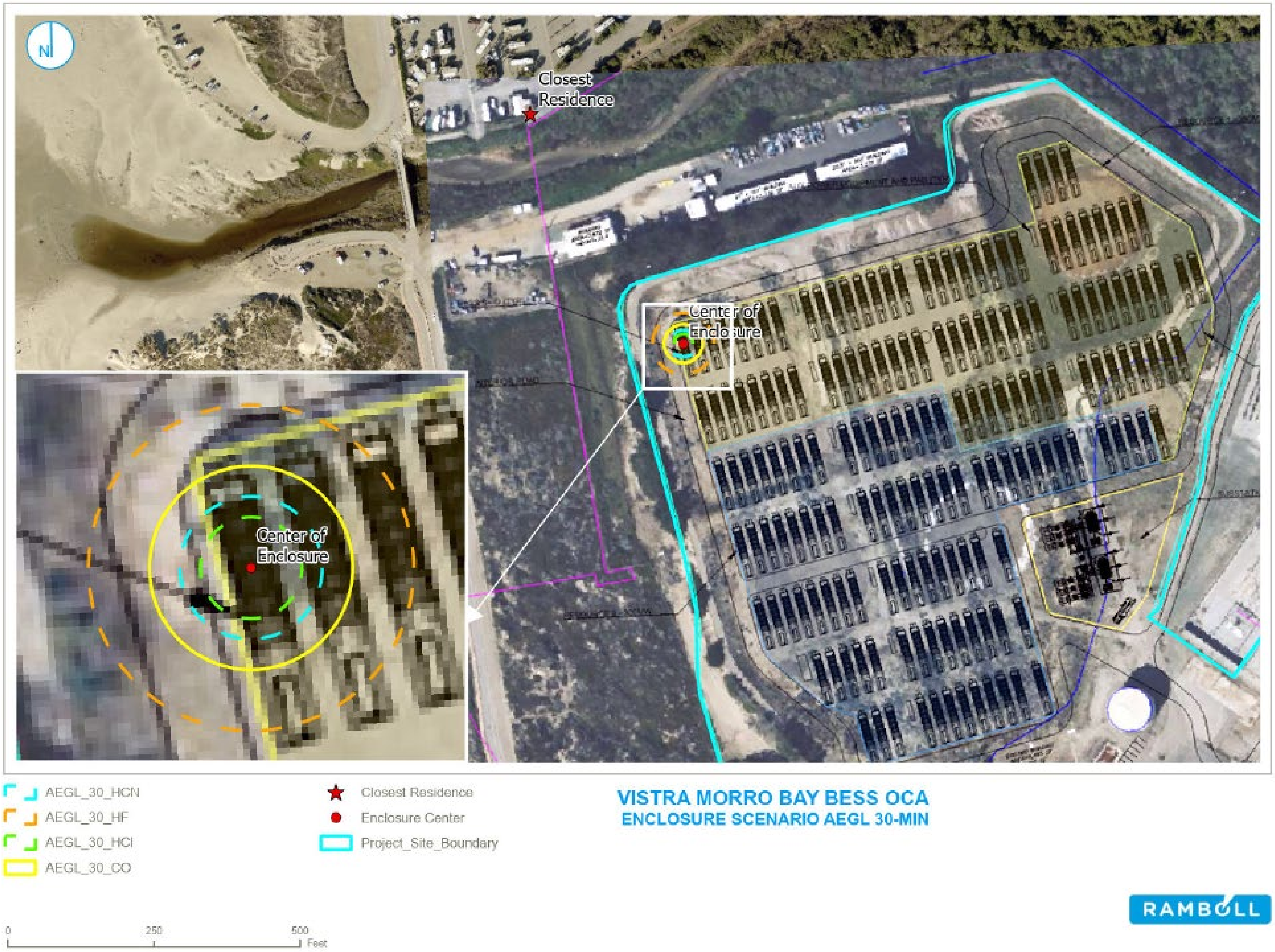

Figure 4-4: AEGL 30-min – Enclosure Alternative

Figure 4-5: AEGL 10-min – Enclosure Alternative

Figure 4-6: AEGL 8-hr – Enclosure Alternative

Figure 4-7: AEGL 8-hr – Proposed Project

5. CONCLUSION

This OCA evaluates the potential risks to the public in the event of a maximum credible fire event at Vistra's proposed BESS facility in Morro Bay, California. The OCA evaluates two potential BESS configurations: one where the batteries are located in buildings (Proposed Project), and one where the batteries are located in separate enclosures (Enclosure Alternative). In preparing this OCA, we reviewed literature prepared by leading experts on BESS safety, past fire incidents, and emissions from battery fires.

This OCA relies on a number of conservative assumptions designed to over-predict potential health and safety impacts to the community. For example, the OCA assumes a maximum credible fire event where an entire block or enclosure of batteries burns over a 24-hour period. We also assumed worst-case weather conditions and other source parameters, such as low wind speeds in the direction of the nearest residence, a low temperature fire, and that the fire occurs at a location closest to the nearest residence.

Using those conservative assumptions, we modeled the resulting concentrations of HF, HCN, HCl, and CO at the nearest residence, which is approximately 132 meters (433 ft) away for the Proposed Project, or 135 meters (443 ft) away for the Enclosure Alternative. These concentrations were compared to applicable health-protective standards for each pollutant to evaluate potential public health and safety risks.

In sum, the proposed BESS project poses no significant risk to the health or safety of the community during a maximum credible event under worst-case conditions.

Appendix A – Summary of Thermal Events at BESS

Ramboll performed an independent review of publicly available databases and other literature concerning historic BESS thermal events. The results of that review are summarized in this Appendix. The sources of data for the information in this Appendix are described below. The information found in these sources is presented in graphical and tabular form below. This represents a reasonable review of the publicly available information, but is not intended to be a definitive list of all possible BESS thermal events that may have occurred.

The Electric Power Research Institute (EPRI) is "…an independent research and development organization to support the electricity sector and address its technical and operational challenges".[138] EPRI created a database for BESS failure events in the United States.[139]

The University of Texas at Austin Database on Battery Fire and Explosion Incidents[140], which uses data provided by Hazard Dynamics, also collects information concerning BESS failure events. This database identifies 43 energy storage incidents worldwide between 2010 to 2022, including incidents in Australia, Korea, China, Japan, and across Europe.[141]

In addition to these databases, Ramboll performed an additional review of publicly available data to identify other energy storage fire or explosion events. Ramboll identified six (6) additional US-based fires, some of which represent repeated or multiple fires at the locations indicated in the University of Texas at Austin Database or owned by the same company.

This review also includes information in the California Public Utilities Commission[142] report on May 31, 2023 that included case studies of safety events worldwide.[143]

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[138] Our History. EPRI. https://www.epri.com/research, accessed on January 29, 2024.

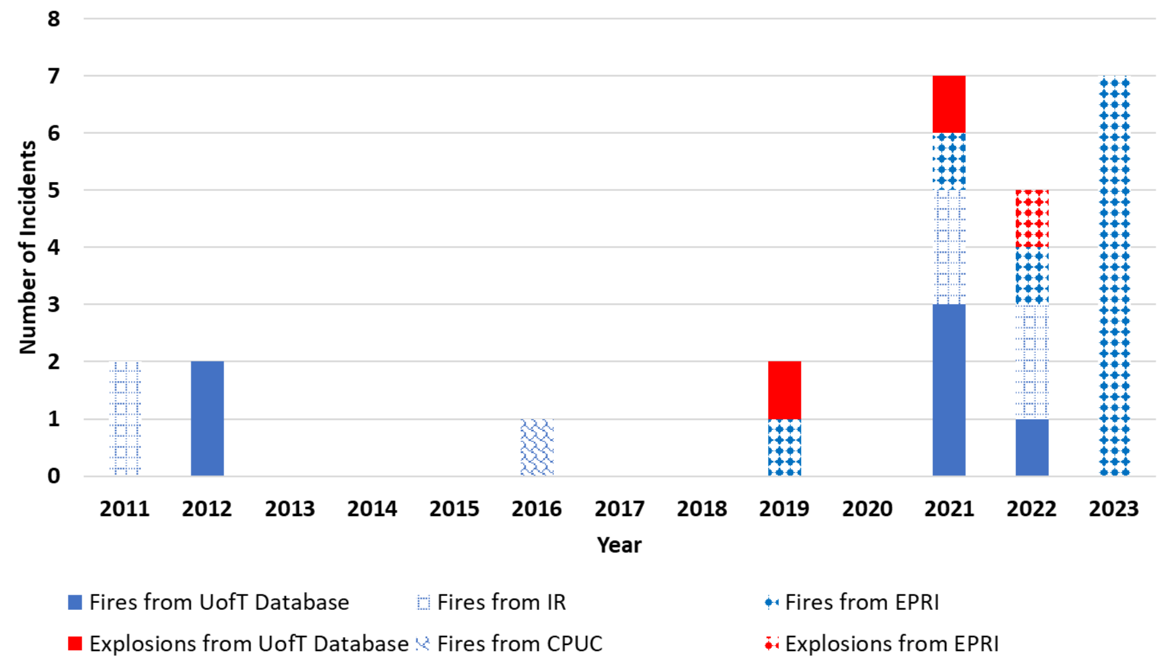
[139] BESS Failure Event Database. EPRI. https://storagewiki.epri.com/index.php/BESS_Failure_Event_Database accessed on January 29, 2024.

[140] The University of Texas at Austin. Battery Fire and Explosion Incidents: Database Tools. http://tools.utfireresearch.com/apps/incident_map, accessed on January 29, 2024.

[141] The University of Texas at Austin. Battery Fire and Explosion Incidents: Database Tools. http://tools.utfireresearch.com/apps/incident_map, accessed on January 29, 2024

[142] California Public Utilities Commission. Energy Storage Procurement Study. 2023-05-31_lumen_energy-storage-procurement-study-report-attf.pdf (ca.gov) accessed on January 29, 2024.

[143] EE Power. S&C Reports on Li-Battery Fire at Its Franklin Facility. S&C Reports on Li-Battery Fire at Its Franklin Facility - News (eepower.com) accessed on January 29, 2024.



*IR indicates independent research or identified by Ramboll.

Figure 4-1: Histogram of fires and explosions according to the sources identified by Ramboll.

Table 4-1: Summary of reported BESS fires in the United States

Location	Date [a]	Duration	Cause	Notes	Type [b]	Reference [c]
Melba, Idaho	02-Oct-23	Approximately 2 days	Defect in unit for water intrusion	2-MW battery system caught on fire. The batteries were lithium iron phosphate.	I	E
Valley Center, California	18-Sep-23	45 minutes	Unknown	A battery storage unit caught fire. No information was given on the capacity of the batteries	I	E
Chaumont, New York	27-Jul-23	Approximately 6 days	Unknown	A cargo container of lithium ion batteries caught on fire. The batteries were used to store electricity from a solar farm. No information was given as to the size of the batteries.	I	E
Warwick, New York	26-Jun-23	Approximately 3 days	Unknown	Two Powin's Centipede LiB storage systems caught on fire. No information was provided for the size of battery that caught on fire.	C	E
East Hampton, New York	31-May-23	Approximately 2 hours	Unknown	5-MW LiB storage system caught fire.	I	E
Millvale, Pennsylvania	30-Jan-23	7 hours	Unknown	Nine LiB were on fire. No information was available for the capacity of the batteries.	C	E
Baker, California	01-Jan-23	Unknown	Unknown	Tesla lithium-ion Megapack used for a mobile Supercharger caught on fire.	C	E
Moss Landing, California	20-Sep-22	Approximately 18 hours	Unknown	Incident was at the PG&E Elkhorn Battery Storage facility from one of the Tesla Megapack LiB located at the facility.	I	IR
Rio Dell, California	03-Aug-22	21 minutes	Unknown	Lead acid batteries were used to store solar energy exploded. The single enclosure of batteries had	C	E

				its roof blown. It is unclear how many batteries were inside the single enclosure.		
Chandler, Arizona	18-Apr-22	14 days	Unknown	The site used LiB. It is not known how many batteries were caught on fire but the facility held 3,000 batteries inside the warehouse.	I	IR
Valley Center, California	05-Apr-22	Unknown	The cause is not known, but only a single battery module was damaged in the fire.	LiB storage meant to provide 140 MW for 4 hours.	I	E
Moss Landing, California	13-Feb-22	Unknown	The cause of the fire was similar to the one that occurred at the same site on September 4, 2021.	The two fires that occurred were at the same site and both used LiBs. This site was the Vistra Moss Landing Phase I and II. The type of batteries was confirmed by the DOE Global Energy Storage Database. The earlier incident detected smoke near 4 enclosures and caused a loss of about 7% of the battery modules (almost 7,000 modules or 320 racks). The second incident had found that 10 battery racks were melted.	I	UT
	04-Sep-21	Unknown	Smoke was detected onsite which triggered water to be sprayed onto the LiB racks, which resulted in overheating and creating more smoke.		I	IR
Cedar City, Utah	29-Jul-21	Unknown	Unknown	Fire occurred in a residential garage for storing solar energy. It is unclear what the type of battery used was.	R	UT
Marseilles, Illinois	19-Jul-21	Unknown	Unknown	Lithium iron phosphate battery storage for frequency	I	E

				regulation. One enclosure containing 720 batteries was affected.		
Morris, Illinois	29-Jun-21	4 days	Unknown	An estimated 184,000 lbs of LiB that were stored in an old paper mill meant for a solar power business caught fire.	I (?)	IR
Berne, New York	07-Jun-21	Not possible to verify		No other reference to this incident was available online. The University of Texas at Austin claimed that the failure was due to lead-acid battery.	R	UT
Bonita Springs, Florida	28-Apr-21	Over 1 hour	Unknown	Lithium batteries at e2comply LLC were caught on fire.	C	UT
Standish, Michigan	19-Apr-21	Unknown	Unclear if the battery caught on fire during installation or testing.	LiB was observed to catch on fire by a worker during installation.	C	UT
Surprise, Arizona	19-Apr-19	Unknown	Internal cell defect.	The site used lithium manganese cobalt (NMC) batteries. Approximately 3 hours after the thermal runaway began, an explosion occurred onsite. One out of the 27 racks of batteries caught on fire.	I	UT
Tualatin, Oregon	12-Apr-19	Unknown	The cause is not known, but it occurred during testing.	Six large LiBs were on fire. No information was available for the capacity of the batteries.	C	E
Franklin, Wisconsin	10-Aug-16	Unknown	Fire began in one of the power and control compartments.	A shipping container that contained partially-assembled system of LiBs were on fire.	C	CPUC
Flagstaff, Arizona	26-Nov-12	Unclear	Battery cell overcharged.	The battery that caught on fire was a 1.5 MWh lithium ion Electrovaya.	I	UT
Kahuku, Hawaii	01-Aug-12	Burned for 13 hours and	Unclear, suspected use	The 3 fires were at the same site. The batteries used were	I	IR

		smoldered for 36 hours.	of undersized capacitors.	lead acid. It is not known how many batteries were affected by the two fires in 2011. The fire in 2012 resulted in the lost of the entire structure housing 12,000 battery packs.		
	23-May-11	Unknown	Suspected manufacturing defect in inverter capacitors and/or undersized capacitors.		I	IR
	22-Apr-11	Over 36 hours			I	UT

[a] Dates highlighted in blue were battery fires and dates highlighted in red were explosions that were reported in the Battery Fire and Explosions Incidents: Database Tools from the University of Texas at Austin.

[b] "R" represents residential application, "I" for industrial, and "C" for commercial.

[c] "UT" represents University of Texas at Austin, "E" for Electric Power Research Institute, and "IR" for independent research by Ramboll personnel