COAST LAW GROUP LLP

1140 S. Coast Highway 101
Encinitas, CA 92024

Tel 760-942-8505
Fax 760-942-8515
www.coastlawgroup.com

October 9, 2017

Mayor and City Council
City of Long Beach
333 West Ocean Blvd
Long Beach CA 90802

VIA ELECTRONIC MAIL
amy.bodek@longbeach.gov

Re: Conditional Use Permit, AES Battery Storage Facility
Long Beach Citizens for Fair Development Appeal

Mayor Garcia and Councilmembers:

Please accept this letter on behalf of our client, Long Beach Citizens for Fair Development (LB Citizens) regarding the AES Battery Energy Storage System (BESS) (Project). As explained below, the Project will result in significant impacts that have not been adequately disclosed or mitigated. As a result, an Environmental Impact Report (EIR) must be prepared.

1. Significant Project Impacts Require Preparation of an EIR

"In reviewing an agency's decision to adopt an MND [Mitigated Negative Declaration], a court (whether at the trial or the appellate level) must determine whether there is substantial evidence in the record to support a 'fair argument' that a proposed project may have a significant effect on the environment." (*Preserve Poway v. City of Poway* (2016) 245 Cal.App.4th 560, 575–76). The fair argument standard is a "low threshold" test for requiring the preparation of an EIR. (*Sierra Club v. County of Sonoma* (1992) 6 Cal.App.4th 1307, 1316-1317; *Oro Fino Gold Mining Corp. v. County of El Dorado* (1990) 225 Cal.App.3d 872, 881). "It is a question of law, not fact, whether a fair argument exists, and the courts owe no deference to the lead agency's determination. Review is de novo, with a preference for resolving doubts in favor of environmental review." (*Pocket Protectors v. City Of Sacramento* (2004) 124 Cal.App.4th 903, 928, emphasis added). If substantial evidence exists to support a fair argument that a significant environmental effect may result from the project, the agency is required to prepare an EIR, irrespective of whether there is other substantial evidence in the record to the contrary. (§ 21080, subd. (d); Guidelines, §§ 15063, subd. (b)(1), 15074, subds. (a), (b); *Preserve Poway, supra*, 245 Cal.App.4th at 576).

2. The Project Will Result in A Significant Impact to Public Views

The Project will result in significant development, including three 65-foot-high 44,500 square-foot buildings. As a result, the Project requires a building height variance. Despite the fact that Long Beach Municipal Code Section 21.21.302(B)(5)(b) requires the installation of story poles for such requests, story poles were not erected due to purported electricity concerns. Instead, visual simulations from publicly-accessible viewpoints were provided. However, not all public views were studied. (See, AES BESS Mitigated Negative Declaration (MND), Key View Locations Map, Exhibit 4.1-1). As reflected in the Southeast Area Specific

Plan EIR, public views from Loynes Drive and East 7th Street/Garden Grove Freeway will be impacted by the massive BESS infrastructure. (See Exhibit A [SEASP Viewshed Map and SEASP excerpts][1]). The 65-foot-tall buildings will also be visible from Pacific Coast Highway (looking west across the wetlands).

In addition, the visual simulations for the Project are not to scale and do not reflect the addition of the Alamitos Energy Center (AEC). (See, Exhibit B, AEC Visual Resources Staff Assessment Appendix, p. 4.3-18 [reflecting additional key observation points; and Exhibit C, AEC Final Staff Assessment Visual Resources [see Figures 1-6]). Lastly, as reflected in the AEC visual simulations, when coupled with the Project, significant cumulative impacts to visual resources will result. (See Exhibit C).

3. Substantial Impacts with respect to Fire and Hazardous Materials Exist

Existing scientific literature and research confirms lithium Ion batteries present a significant fire hazard. (See Exhibit D, Lithium Ion Batteries, A Fire Potential In Waiting; Exhibit E[2], U.S. Department of Energy, Storage Safety Strategic Plan).

> Evolution of H2 from lead-acid cells or H2 and solvent vapor from lithium-ion batteries during overcharge abuse could results in a flammable/combustible gas mixture. Thermal runaway in lithium-ion (Li-ion) cells could transfer heat to adjacent cells and propagate the failure through a battery. Moreover, while physical hazards are often considered, health and environmental safety issues also need to be evaluated to have a complete understanding of the potential hazards associated with a battery failure. These may include the toxicity of gas species evolved from a cell during abuse or when exposed to abnormal environments, toxicity of electrolyte during a cell breech or spill in a Vanadium redox flow battery (VRB),environmental impact of water runoff used to extinguish a battery fire containing heavy metals. (Exhibit E, pp. 22-23).

Because they contain electrolytes, lithium ion batteries are particularly flammable and pose significant environmental and health risks:

> Lithium ion batteries are more efficient than lead acid batteries and therefore can take up less space. Lithium ion batteries contain flammable liquid electrolyte that may vent, ignite and produce sparks when subjected to high temperatures, damaged or abused (e.g., mechanical damage or electrical overcharging). Lithium ion batteries may burn rapidly with flare-burning effect and may ignite other batteries or combustibles in close proximity. Contact with the electrolyte in the lithium ion battery may be irritating to skin, eyes and mucous membranes. Fire will produce irritating, corrosive and/or toxic gases including hydrogen fluoride gas. (Exhibit F, p. 33 [Cal-Fire, Fire Operations for Photovoltaic Emergencies]).

Notably, the Department of Energy found current regulations and simple installation of fire

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[1]See Chapter 4, pp. 76-77 View Development Standards reflecting public views to water areas and open space must be maintained and enhanced and new developments along view corridors should demonstrate how the project will maintain or *restore* views into the SEASP area.

[2] Also available at http://www.datacenterjournal.com/lithium-ion-li-ion-batteries-a-fire-potential-in-waiting/

sprinklers are likely insufficient to address lithium ion battery fires:

> Current commodity classification systems used in fire sprinkler design (NFPA 13-Standard for Installation of Sprinkler Systems) do not have a classification for lithium or flow batteries. This is problematic, as the fire hazard may be significantly higher depending on the chemicals involved and will likely result in ineffective or inaccurate fire sprinkler coverage. Additionally, thermal decomposition of electrolytes may produce flammable gasses that present explosion risks. Better understanding of these gases and the combustion process of the overall battery chemistry is needed to identify adequate fire protection systems. (Exhibit E, p. 48, emphasis added).

As reflected above, battery storage is an emerging technology which has outpaced regulatory updates. (See Exhibit G, National Fire Protection Organization, Power to Spare).[3] A 2016 Fire Protection Research Foundation report entitled "Hazard Assessment of Lithium Ion Battery Energy Storage Systems" found "several gaps" in review of electrical, fire and building codes as well as knowledge gaps based on limited experience with real world fire incidents. (See Exhibit H, Hazard Assessment of Lithium Ion Battery Energy Storage Systems, pp. 78-80).

Therefore, reliance on typical fire safety and hazardous material regulations will not address or mitigate the substantial risk of fire and hazardous material exposure. (See, Response to Comments, August 3, 2017, pp. 5-7). As a result, the MND's reliance on monitoring and standard sprinklers is inappropriate and insufficient to mitigate the potential significant impact of the Project's 70,000 to 90,000 gallons of flammable electrolyte. (See, MND, Section 4.8; see *Protect The Historic Amador Waterways v. Amador Water Agency* (2004) 116 Cal.App.4th 1099, 1109 ["In each instance, notwithstanding compliance with a pertinent threshold of significance, the agency must still consider any fair argument that a certain environmental effect may be significant."]).

Moreover, the Project's proximity to sensitive receptors such as wetlands and residential areas exposes such receptors to substantial risk of exposure to hazardous materials and fire. (See Exhibit I, Campo Verde Battery Energy Storage System DEIR, Section 4.5 Hazards and Hazardous Materials). The Campo Verde BESS project DEIR details numerous additional design features and mitigation measures to address the potential fire hazard, including a fire suppression gas agent that is electrically non-conductive, a FM 200 fire suppression system, structural integrity to retain the gas, monitoring of the electric actuator, detectors, warning devices, cylinder pressure, and any manual release and abort stations, and early warning detection devices. (Exhibit I, p. 4.5-14). These and other mitigation measures and design features were required *in addition to* compliance with the California Fire Code Requirements. (See, Exhibit I, pp. 4.5-14-16). The MND does not reflect similar features incorporated into the Project. As a result, the Project's impacts from fire and hazardous materials remain significant and unmitigated.

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[3] Also available at http://www.nfpa.org/news-and-research/publications/nfpa-journal/2016/january-february-2016/features/ess

4. Conclusion

In light of the significant environmental impacts that remain, we urge the Council to approve the appeal and require preparation of an EIR. Thank you in advance for your consideration of our comments.

Sincerely,

COAST LAW GROUP LLP

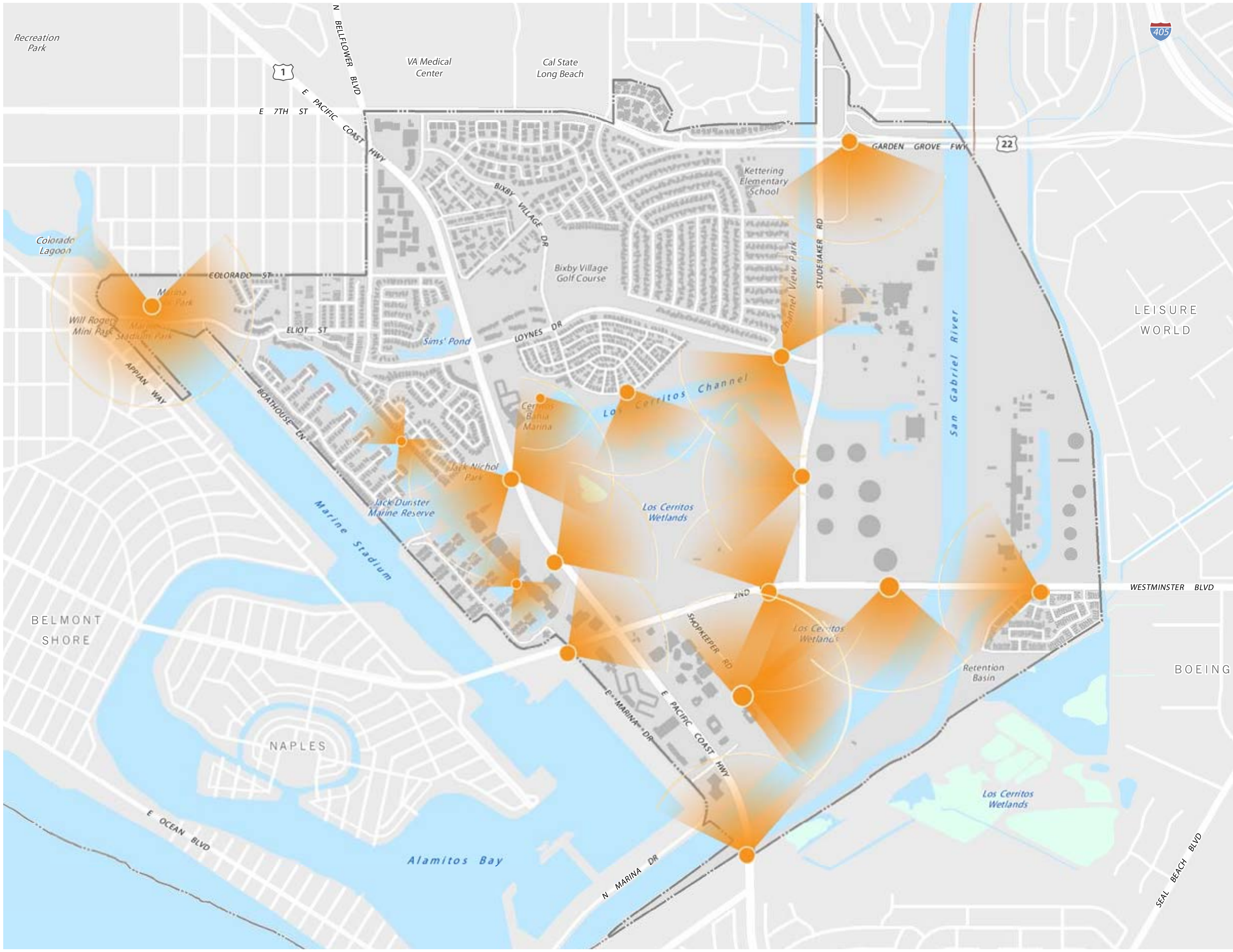
Livia Borak Beaudin
Attorneys for
Long Beach Citizens for Fair Development

Enclosure: Exhibits A-I

cc:

Mayor: Mayor@longbeach.gov;
Councilmembers: district1@longbeach.gov; district2@longbeach.gov; district3@longbeach.gov; district4@longbeach.gov; district5@longbeach.gov; dee.andrews@longbeach.gov; district7@longbeach.gov; district8@longbeach.gov; district9@longbeach.gov
Client

Figure 4-3 Public View Sheds



Public View Shed

Specific Plan Boundary

City Boundary

NOTES: A distinguishing characteristic of the SEASP area is the extensive view opportunities to water and wetland resources that can be found throughout the community. Views can be found along prominent corridors (PCH south of the Los Cerritos Channel to the County line), urban water edge views (behind Marina Pacifica), and open edge views (views into the Los Cerritos Wetlands from adjacent uses and roadways). Restoring and maintaining view opportunities is an essential component of the SEASP Vision—from water to wetlands. This graphic is not meant to be exhaustive of all the existing public views in SEASP. Instead, it illustrates examples of the many locations where views to nearby water and wetlands, or the mountains in the distance, are present throughout the southeast area.

While views can be from both public and private areas, the Specific Plan only provides direction to regulate and preserve public views, and does so in Chapter 7, Design Standards and Guidelines.

Source: PlaceWorks

0 400 800 1,200 Feet

c. Open Space and Amenities In Mixed-use Designations

A variety of public open spaces throughout SEASP is needed to serve residents, workers, and visitors. All new development in the SEASP area is required to provide open space as outlined below and in Table 5-9, *Open Space Requirements for Mixed-use Areas*.

- » Allowed types of open space include common outdoor open space, such as public plazas and paseos, and private open space, such as balconies and internal courtyards typically associated with residential uses.
- » Public open spaces should include flexible areas for public gatherings, such as lawn area or a paved plaza, at a scale that maintains intimacy, form, and character and also contributes to a well-connected public realm.
- » Public plazas shall be located at intersections or adjacent to midblock pedestrian crossings and be prominently integrated with internal sidewalks and streets. Plazas at corners are encouraged to include outdoor dining space for adjacent restaurants.
- » Public plazas shall be located along view corridors or view edges (Waterway Promenade) to provide additional opportunities to maximize the public's opportunity to experience the water and wetlands amenities in SEASP.
- » Required build-to lines and street setback areas cannot be used to satisfy required open space areas.
- » The Site Plan Review Committee may consider alternate configurations and amounts of open space on a project-specific basis, if such changes would be consistent with the intent and goals of this plan.
- » Developers shall construct public open space, trails, pathways, and bicycle trails for each development in a manner that will be generally accessible to the public and that will interconnect with similar facilities in adjacent developments so as to form an integrated system of open space and trails connecting activity centers, important views, and destinations in the SEASP project area.
- » Usable open space is defined as any public or private space on a lot not enclosed within a building that is designed for specific recreational purposes, including active and passive recreational or gathering activities.
- » Usable open space includes yards (except the required front yard setback), courtyards, plazas, paseos, balconies, decks, porches, roof decks, and patios. Indoor gyms associated with a residential or hospitality use may also be counted as usable open space. Usable open space does not include driveways, aisles, parking spaces, or side or rear yards less than eight feet (8') in width, or front yards unless permitted by the provisions of Section 21.31.242.
- » Bicycle and pedestrian trails not included within the public right-of-way may be considered usable open space.
- » Usable open space can be located above grade, including on rooftops, decks, patios, and the like.

d. Views

The scenic and visual qualities of coastal areas shall be considered and protected as resources of public importance as specified in the California Coastal Act Section 30251. The policies below reflect this mutual objective of the Specific Plan and the Coastal Act.

- » Public views to water areas and public open spaces shall be maintained and enhanced to the maximum extent possible.
- » Permitted development shall be sited and designed to protect views to (and along) the ocean and scenic coastal areas, to minimize the alteration of natural landforms, to be visually compatible with the character of surrounding areas, and, where feasible, to restore and enhance visual quality in visually degraded areas.

Table 5-10 Bicycle Parking Requirements

Use	*Minimum Bicycle Capacity*	*Suggested Type of Parking Facility*	*Location*
Multifamily Residential	1.0 space per 2 units, 1 enclosed locker required for every 50 dwelling units	A-frame or freestanding rack	Near main entrance with good visibility, not to obstruct auto or pedestrian movement.
Commercial/ Office	1.0 space per 5,000 sq. ft. of building area	Staple or new technology	
Retail	1.0 space for each 7,500 sq. ft. of building area	Staple or new technology	
Schools	8.0 spaces per 40 students	A-frame or freestanding racks	Near office entrance with good visibility, in fenced area.
Public Facilities	8.0 spaces per location	Staple or freestanding racks	Near office entrance with good visibility.
Hotel	1.0 space per 25,000 sq. ft. of building area	A-frame or freestanding racks	Near entrance with good visibility.

NOTE: Calculations that result in a fraction of 0.5 or higher shall be rounded up to the nearest whole number.

New development in areas adjacent to edge views, in view corridors, or areas with public view sheds, such as those illustrated in Figure 4-2, *Community Structure*, Figure 4-3, *Public View Sheds*, and Figure 7-1, *View Opportunity Areas*, shall provide renderings with project submittal that illustrate how views from grade will look with a proposed new development. Illustrations or photo-simulations should demonstrate how the project will maintain or restore edge views or important view corridors into the project area.

e. Landscape

» Landscaping for projects (including right-of-way medians) within SEASP shall be consistent with the provisions of Chapter 21.42, *Landscape Standards*, in the Zoning Code. Landscaping shall be consistent with the efficiency standards in Title 21 of the California Building Code as well.

» For projects within the Mixed-Use Community Core and Mixed-Use Marina areas, the provisions of Chapter 21.42, *Landscaping Standards,* for R-3, R-4, and Nonresidential Districts shall apply.

» Landscaping shall be drought-tolerant and feature native, non-invasive, adaptive plants (per CALGreen standards and Cal-IPC species) to create a more seamless transition between the natural wetlands and development. Plant materials selected for each project shall comply with Appendix D, *Plant Palette*. Projects in mixed-use designations shall utilize at least 75 percent native California plant and tree species appropriate for the climate zone region (per Section A4.106.3 of CALGreen, 2013).

f. Parking

» Minimum parking (vehicular parking) for residential and nonresidential uses shall be the same as required Citywide by the zoning code for each use; except that, in that part of SEASP within the Coastal Zone, Coastal Zone standards shall apply.

» Minimum parking for commercial and industrial uses shall be provided in accordance with parking standards as specified in the zoning code.

» Shared, bundled, or pooled parking, off-site parking, or valet parking plans are permitted within the SEASP subject to approval by the Site Plan Review Committee.

» Electric vehicle charging facilities are encouraged and must comply with the applicable provisions of the LBMC.

DOCKETED

Docket Number:	13-AFC-01
Project Title:	Alamitos Energy Center
TN #:	213943
Document Title:	Visual Resources Final Staff Assessment Appendices
Description:	This document includes Visual Resources Appendices VR-1 and VR-2. Appendix VR-1 provides Visual Resources terms, definitions and analysis method. Appendix VR-2 provides the Key Observation Point Evaluation Matrix and Visual Impact Determination Conclusions in a table format. These appendices were inadvertently omitted from the Final Staff Assessment for the Alamitos Energy Center Project When docketed on September 23, 2016.
Filer:	Jonathan Fong
Organization:	California Energy Commission
Submitter Role:	Commission Staff
Submission Date:	10/10/2016 3:04:02 PM
Docketed Date:	10/10/2016

STATE OF CALIFORNIA - NATURAL RESOURCES AGENCY EDMUND G. BROWN, JR., Governor

CALIFORNIA ENERGY COMMISSION
1516 NINTH STREET
SACRAMENTO, CA 95814-5512
www.energy.ca.gov

October 10, 2016

This document includes Visual Resources Appendices VR-1 and VR-2. Appendix VR-1 provides Visual Resources terms, definitions and analysis method. Appendix VR-2 provides the Key Observation Point Evaluation Matrix and Visual Impact Determination Conclusions in a table format. These appendices were inadvertently omitted from the Final Staff Assessment for the Alamitos Energy Center Project When docketed on September 23, 2016.

Sincerely,

Date: October 10, 2016 Signature on file
KEITH WINSTEAD
Planner III
Siting, Transmission, & Environmental Protection Division

VISUAL RESOURCES APPENDIX-1

VISUAL RESOURCES APPENDIX-1
VISUAL RESOURCES TERMS, DEFINITIONS, AND ANALYSIS METHOD

This appendix is divided into two main sections. The first section defines key terms and describes the method used by Energy Commission staff (staff) to evaluate effects of a project on visual resources. The second section describes the process to evaluate effects of publicly visible water vapor plumes on visual resources.

Staff conducted a preliminary analysis of the proposed project's exhaust gas characteristics and ambient air conditions and determined that conditions would be unlikely to cause formation of visible plumes above the project's exhaust stacks. Therefore, the section of this appendix pertaining to visible plumes is not applicable to the proposed project.

KEY TERMS AND ANALYSIS METHOD

VISUAL SPHERE OF INFLUENCE AND DISTANCE ZONES

The *visual sphere of influence* (VSOI) depicts the area within which the proposed project could cause significant impacts on visual resources. The extent of the VSOI will vary depending on the project setting, topography, and the presence or absence of natural or built screening, and it must be determined on a case-by-case basis. For projects in urban settings, visibility of a project site may be limited to specific vantage points in the VSOI. For projects in relatively open areas, a project site may be visible throughout most of the VSOI.

A VSOI boundary may be refined to account for local viewing conditions and topographic screening based on computer *viewshed* analysis and mapping, which is a useful way to determine project visibility and to communicate that information to others. A viewshed is the surface area visible from a given viewpoint or series of viewpoints. It is also the area from which that viewpoint or series of viewpoints may be seen. At a basic level, a viewshed is a plan view or map of areas with an unobstructed sightline to a single observer viewpoint (Federal Highway Administration 1990).

The VSOI may be mapped up to a distance of approximately five miles from a project site. At the limits of the VSOI, distant background features may blend together such that they would not be especially discernible to the viewer.

Visual resource management guidelines and methods established by federal agencies are often adapted and used by staff to evaluate the impacts of a project on visual resources. The visual management system of the U.S. Forest Service uses distance zones to describe parts of a characteristic landscape that is subject to inventory and evaluation (Bacon 1979). The Federal Highway Administration (FHWA) uses similar descriptions for distance zones (FHWA 1990). Staff includes a discussion of distance zones to describe views of the project site from parts of the VSOI, which are described as follows:

- **Foreground**. This zone will usually be limited to areas within one-quarter to one-half mile of the observer, but must be determined on a case-by-case basis as should any distance zoning. The limit of this zone is based on distances at which details can be perceived. For example, the viewer may see the texture and form of individual plants or tree boughs. Intensity of color and its value will be at a maximum level.
- **Middleground**. This zone may extend from the foreground zone to three to five miles from the observer. Texture is generally characterized by masses of trees in stands of uniform tree cover. Parts of the landscape may be seen to join together; hills become a range or trees appear as a forest. Individual tree forms are usually only discernible in very open or sparse stands.
- **Background**. This zone may extend from the middleground zone to infinity. The surfaces of land forms lose detail distinctions, and the emphasis is on the outline or edge of the land forms. The texture in stands of uniform tree cover is generally very weak or nonexistent. In open or sparse timber stands, texture is seen as groups or patterns of trees. Atmospheric haze may diminish colors, soften features, and reduce contrast in background views.

Visual elements closer to the viewer will be in the foreground or middleground. Visual elements at the limits of the project VSOI will generally be those that appear in the background.

VISUAL ABSORPTION CAPABILITY

Visual absorption capability (VAC) provides an additional perspective on the landscape and its capacity to visually withstand or absorb changes from a project. VAC is an estimate or measure of the capacity of a landscape to absorb visual alterations without significantly affecting visual character (Bacon 1979). High VAC may be associated with varied, undulating landforms and varied vegetation canopy. Low VAC may be associated with a uniform landscape, an even tree canopy, and steep slopes. (As the upward slope increases, a greater area of land becomes directly visible and any intervening vegetation loses the potential to screen the activity.)

SELECTION OF KEY OBSERVATION POINTS

Sensitive viewing areas are identified and inventoried in the VSOI for a project where project structures and facilities could be visible to the public. A list of sensitive viewing areas could include several types of uses:

- residential;
- recreational, including wildlife areas, parks, visitor centers, hiking trails, and other recreation areas;
- travel routes, including major roads or highways and designated scenic roads; and
- tourist destinations, including historic landmarks and other protected natural and built features in the landscape.

Refinement of the visual analysis for a project involves identifying critical viewpoints, or key observation points (KOPs). KOPs are selected to represent the most critical viewpoints from off-site locations where a project would be visible to the public.

Because it is infeasible to analyze all viewpoints, KOPs are selected that would most clearly display the visual effects of the proposed project. A KOP may also represent a primary viewer group(s) (e.g., motorists on a highway in the project area) that could potentially be affected by a project.

Following selection of the KOPs, photographs are taken of the project site to show existing conditions from the KOPs. The existing condition (baseline) photographs taken from the selected KOPs are used to prepare representative visual simulations of the proposed project or specific project feature. The simulations portray the relative scale and extent of the project. The photograph of the existing condition and the visual simulation (proposed condition) are reviewed for each KOP to determine the potential effects of a project on visual resources.

PROCESS TO EVALUATE KEY OBSERVATION POINTS

VISUAL SENSITIVITY (EXISTING CONDITION)

Steps to evaluate the overall visual sensitivity for each KOP involve consideration of several key factors: *visual quality, viewer concern, visibility, number of viewers,* and *duration of view*. In a project analysis, the rating scale ranges from low to high for each factor. These factors are also used to convey the overall scenic value of the view from each representative KOP. The five factors are described below. (Diagram 1 [below] illustrates the process to evaluate the KOPs and determine impact significance.)

Visual Quality

Visual quality is an expression of the visual impression or appeal of a given landscape and the associated public value attributed to the visual resource. The visual quality of an area is composed of visual or scenic resources, which are those physical features that make up the visible landscape, including land, water, vegetation, and the built environment (e.g., buildings, roadways, irrigation canals, and other structures). Scenic resources that compose scenic views and sites are generally valued for their aesthetic appearance. Using staff's visual resources analysis method, visual quality is generally rated from low to high.

Memorable or visually powerful landscapes are generally rated high when the landscape components combine in striking or distinctive visual patterns. Landscapes with high visual quality are visually coherent and harmonious when each element is considered as part of the whole. The landscapes are free from encroaching elements and thus retain their visual integrity. Landscapes rated low are often dominated by visually discordant built elements. **Table 1** describes a set of ratings associated with an assessment of visual quality.

Table 1
Landscape Scenic Quality Scale

Rating	Description
Outstanding Visual Quality	This rating describes landscapes with exceptionally high visual quality. These landscapes are often significant regionally and/or nationally, and they usually contain exceptional natural or cultural features that contribute to this rating. They might be described as “picture-postcard” landscapes. People are attracted to these landscapes to view them. These landscapes are often managed in a manner to ensure preservation of the inherent qualities of the landscape.
High Visual Quality	Landscapes with high visual quality may contain cultural or natural features in the landscape that attest to their value. These landscapes often contain visually interesting spaces and elements that are arranged in ways that make them particularly pleasant places to be. Areas with high visual quality often provide recreational opportunities where the visual experience is important. These landscapes are often managed to emphasize preservation of the inherent qualities of the landscape.
Moderately High Visual Quality	These landscapes have above average scenic value but do not possess all of the qualities associated with places that are rated high. The scenic value of these landscapes may be lower due to the less interesting arrangement of landscape elements. These landscapes may have recreational potential, and visual quality is an important management concern.
Moderate Visual Quality	These landscapes have average scenic value and are not especially memorable. They usually lack noteworthy cultural or natural features. These landscapes may have considerable recreational potential and visual quality is a management consideration.
Moderately Low Visual Quality	These landscapes have below average scenic value. They may contain visually discordant built elements, but the landscape is not dominated by these features. They often provide little visual interest and lack spaces that people will perceive as inviting. Recreational activities may occur in areas with below average scenic value, but the visual experience for recreationists is less important in these areas. Management concerns for visual quality may be limited to minimizing the adverse visual impacts of resource management activities or projects.
Low Visual Quality	Landscapes with low scenic value may be dominated by visually discordant built elements. They do not include places that people will find inviting, and lack attributes that make areas with higher quality views memorable and visually interesting. These landscapes often have little recreational potential. Management concerns for visual quality may either address rehabilitation of visually discordant built elements or are limited to minimizing the adverse visual impacts of resource management activities or projects.
Source: Adapted from Buhyoff et al., 1994	

Viewer Concern

Viewer concern represents the estimated reaction of a viewer or viewer group to visible changes in the view. Viewer concern will vary depending on the characteristics and preferences of the viewer group. An assessment of viewer concern can be made based on the extent of the public’s concern for a particular landscape or for scenic quality in general. Existing discordant elements in the landscape may temper viewer concern.

Viewer concern for homeowners or other local residents is expected to be high for views near their homes. Viewers engaging in recreational activities and enjoying scenic surroundings are generally expected to be highly concerned about potential degradation of the existing visual quality and character of their views.

Viewer activity is an identifying characteristic of viewer groups (FHWA 1990). Commuting in heavy traffic can distract an observer from many aspects of the visual environment; therefore, viewer concern tends to be lower for views seen by people driving to and from work or as part of their work. Employees, managers, and patrons of businesses may have extended and repeated views of their surroundings on a daily basis. This viewer group may have lower expectations for visual elements in the VSOI than residents and recreationists.

The viewer concern of motorists generally depends on when and where travel occurs, the angle of view, the view distance, and the frequency of travel of the motorist in a particular area. As the observer's speed increases, the sharpness of lateral vision declines, and the observer tends to focus along the line of travel. It is assumed that motorists on freeway systems during periods of free flow travel have a low to moderate viewer concern. Daily commuters using inner city freeways in heavy traffic are primarily focused on traffic and roadway conditions along the travel corridor. Commuters traveling at normal freeway speeds are generally more aware of views from the freeway. Motorists driving for pleasure are expected to have a higher concern for view. Motorists who are local residents and/or business owners may have a higher viewer concern due to their personal investment in the area and greater familiarity with the local environment.

In urban and semi-rural settings, individual viewers are likely to include employees and managers working in offices and commercial and industrial businesses. In rural and semi-rural areas, individual viewers may include people employed in agricultural, industrial, and commercial businesses. For viewers whose focus is on their work and daily pursuits, viewer concern is generally expected to be low to moderate. However, this rating will vary depending on the existing visual quality of the landscape and built environment.

Scenic roadways, cultural features, or other areas identified in adopted land use planning documents are subject to protection. The scenic qualities of protected resources are recognized for their value to the public, and the expectation of viewers is that views of protected resources will be preserved.

Visibility

An assessment of visibility addresses how well the project site or feature can be seen from a particular location. The degree of visibility generally depends on the angle or direction of view; extent of visual screening provided by built and/or natural elements; topography; and the distance between the object (i.e., the project site) and existing homes, streets, or parks. In this sense, visibility is determined by considering any and all obstructions that may be in the sightline, including trees and other vegetation, buildings, hills, and transmission poles or towers.

Number of Viewers

This is an estimate of the number of viewers who may see the project site or feature. The estimate is based on the number of residences, the average traffic volume on local roads and highways, and the number of recreational users per day (e.g., the number of people participating in any recreational activity during a 24-hour period). Traffic volume is based on data such as average daily vehicle trips (ADT) or annual average daily vehicle trips (AADT).

For recreational users, the number of viewers is closely tied to visual quality and viewer concern. For recreationists engaged in activities where visual quality is on the higher end of the scale, the number of viewers is carefully considered in the visual assessment. For example, a recreational area in an area with a high visual quality rating may receive a higher rating overall regardless of the number of viewers. For example, a visual change at a national park is generally more important than a visual change near a large sports stadium.

Table 2 shows ratings based on estimated numbers of viewers. Variations in viewer preferences and existing visual quality will influence these ratings.

Table 2
Approximate Number of Viewers By Viewer Category and Corresponding Rating

Residential (number of residences	Recreationists (number of people per day)	Motorists (number of motor vehicles per day)	Rating
Over 100	Over 200	Over 10,000	High
50–100	100–200	5,000–10,000	Moderate to High
20–50	50–100	2,500–5,000	Moderate
5–20	25–50	500–2,500	Low to Moderate
2–5	10–25	125–500	Low
Source: Energy Commission staff			

Duration of View

Duration of view is the estimated length of time a project site is viewed by a person or group of people. The importance of view duration varies depending on the activities of the viewers. Duration of view is generally less of a concern when the viewer only briefly glimpses the visible feature or site. However, if the site is subject to viewing for a longer period, as from a scenic overlook, then duration of view is a factor of greater importance. Residential viewers typically have the longest duration of view. A resident with a direct view of a project site might have views lasting for extended periods depending on the orientation of the residence and the extent of visual screening.

For motorists, the duration of view depends on the speed of travel, view distance, and angle of observation. For a motorist traveling at 60 miles per hour on a highway with a direct view of a project site, and where the initial point of visibility is approximately one mile away, the viewer might see the site for a continuous 60-second period.

The duration of view for recreationists will vary depending on whether the recreational activity is *active* or *passive*. Active recreation involves direct participation in a sport or play activity, which typically requires the use of an organized space (e.g., off-road bike trails or a team sports field). A view of a proposed project by people observing or engaging in active recreation is estimated to be of short duration. People engaging in recreational activities under these conditions are likely to be focused on the sport rather than the aesthetics of the environment.

Passive recreation often involves low impact activities or observation and does not require use of an organized play or sports area. Viewers are more closely associated with the surrounding physical environment where the activity takes place. Typical activities include climbing, hiking, wildlife observation, fishing, and picnicking. A view of a proposed project by an individual engaged in passive recreation is estimated to be of longer duration than for someone participating in active recreation.

Table 3 provides a baseline to determine the ratings associated with view duration. As with number of viewers, variations in viewer preferences and existing visual quality will influence the relative importance of the ratings for duration of view.

Table 3
Approximate Duration of View and Corresponding Rating

Approximate Duration of View	Rating
Longer than 2 minutes	High (extended period of time)
1–2 minutes	Moderate to High
20–60 seconds	Moderate (mid-length period of time)
10–20 seconds	Low to Moderate
Less than 10 seconds	Low (brief period of time)
Source: Energy Commission staff	

Overall Viewer Exposure

Overall viewer exposure is based on *visibility*, *number of viewers*, and *duration of view*. These three factors are generally given equal weight in determining overall viewer exposure. However, additional weight is given to any factor with an extreme value. For example, if a project's visibility is very limited because it would be almost entirely screened from public view, staff gives a lower value to overall viewer exposure.

Overall Visual Sensitivity

Overall visual sensitivity is based on *visual quality*, *viewer concern*, and *overall viewer exposure*. These three factors are generally given equal weight in determining the level of overall visual sensitivity.

VISUAL CHANGE (PROPOSED CONDITION)

The visual change for each KOP is described using the terms *contrast*, *dominance*, and *view blockage*. The scale for rating the visual change ranges from low to high for each factor. The three factors used to evaluate visual change are described below.

Contrast

The degree to which a project could affect the visual quality of a landscape generally depends on the visual contrast created between a project and the existing landscape (U.S. Bureau of Land Management 1986 and 2012). The basic design elements of form, line, color, and texture are used for this comparison and to describe the visual contrast created by a project:

- **Form**. Contrast in form results from changes in the shape and mass of landforms or structures. The degree of change depends on how dissimilar the introduced forms are to those that exist in the landscape.
- **Line**. Contrasts in line results from changes in edge types and interruption or introduction of edges, bands, and silhouette lines. New lines may differ in their sub-elements (e.g., boldness, complexity, and orientation) from existing lines.
- **Color**. Changes in value, or a gradation or variety of a color (hue) tend to create the greatest contrast. Other factors such as saturation of a color, reflectivity, color temperature, may also increase the contrast.
- **Texture**. Noticeable contrast in texture usually stems from differences in the grain, density, and internal contrast. Other factors such as irregularity and directional patterns of texture may affect the rating.

Projects designed to repeat forms, lines, colors, and textures as those present in the existing landscape will generally be less noticeable. (See also the discussion above under "Visual Absorption Capability.") **Table 4** provides a baseline for the degree of contrast rating.

Table 4
Degree of Contrast and Corresponding Rating

<table>
<tr><th>Criteria</th><th>Rating</th></tr>
<tr><td rowspan="2">The element contrast demands attention, will not be overlooked, and is dominant in the landscape.</td><td>High (strong)</td></tr>
<tr><td>Moderate to High</td></tr>
<tr><td>The element contrast begins to attract attention and begins to dominate the characteristic landscape.</td><td>Moderate</td></tr>
<tr><td rowspan="2">The element contrast can be seen but does not attract attention.</td><td>Low to Moderate (weak)</td></tr>
<tr><td>Low</td></tr>
<tr><td>The element contrast is not visible or perceived.</td><td>None</td></tr>
<tr><td colspan="2">Source: Adapted from U.S. Bureau of Land Management 1986</td></tr>
</table>

Dominance

Dominance is a measure of (a) the proportion of the total field of view that the proposed feature occupies, (b) a proposed feature's apparent size relative to other visible landscape features, and (c) the conspicuousness of the proposed feature due to its location in the view. Also, forms that are bold, regular, solid, or vertical will tend to dominate the landscape.

A proposed feature's level of dominance may be lower in a panoramic setting than in an enclosed setting with a focus on the feature itself. A feature's level of dominance is higher if it is (a) near the center of the view, (b) elevated relative to the viewer, or (c) has the sky as a backdrop. As the distance between a viewer and a feature increases, the feature's apparent size decreases and its dominance decreases as a consequence. The level of dominance is rated from low (subordinate) to high (dominant).

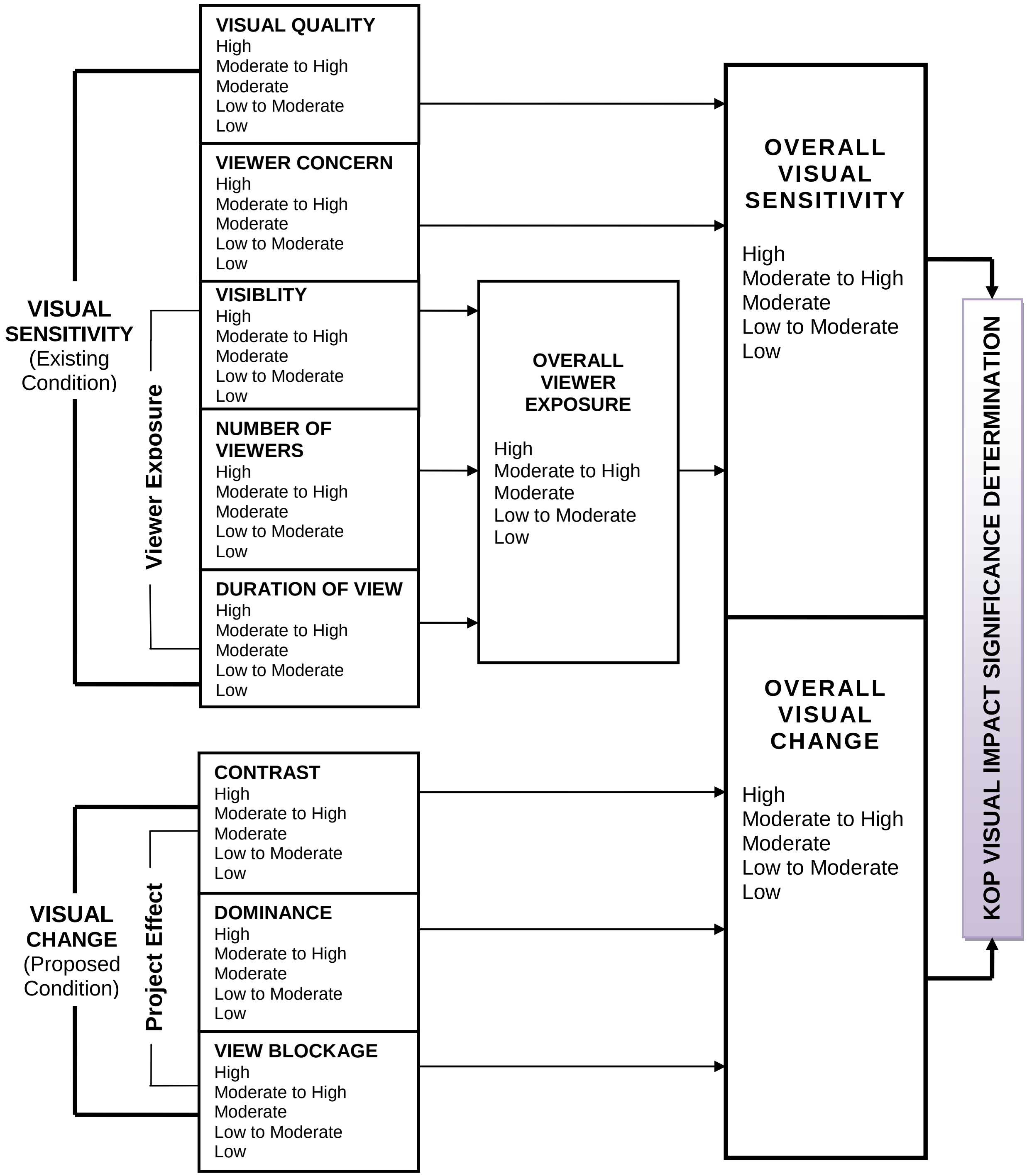
View Blockage

View blockage is the extent to which an existing publicly visible landscape feature (built or natural elements) would be blocked from view by the proposed project. The view is also disrupted when the continuity of the view is interrupted. Higher quality landscape features can be disrupted by the introduction of lower quality features into the view. The degree of view blockage is rated from low to high.

Overall Visual Change

Overall visual change is based on *contrast*, *dominance*, and *view blockage*. These factors are given equal weight in an assessment of overall visual change. Overall visual change is rated from low to high.

VISUAL RESOURCES Diagram 1- Key Observation Point Evaluation



VISUAL IMPACT SIGNIFICANCE DETERMINATION

Visual impact significance is based on the ratings for *overall visual sensitivity* and *overall visual change*. The ratings for overall visual sensitivity and overall visual change are combined to determine significance of the visual impact for each KOP (**Table 5**).

Table 5
KOP Visual Impact Significance Determination

Overall Visual Sensitivity	**Overall Visual Change**				
	High	**Moderate to High**	**Moderate**	**Low to Moderate**	**Low**
High	Significant	Significant	Significant	Less Than Significant	Less Than Significant
Moderate to High	Significant	Significant	Potentially Significant	Less Than Significant	Less Than Significant
Moderate	Significant	Potentially Significant	Less Than Significant	Less Than Significant	Less Than Significant
Low to Moderate	Less Than Significant	Less Than Significant	Less Than Significant	Less Than Significant	No Impact
Low	Less Than Significant	Less Than Significant	Less Than Significant	No Impact	No Impact

Notes:

“Significant effect on the environment” means a substantial, or potentially substantial, adverse change in any of the physical conditions within the area affected by the project, including land, air, water, minerals, flora, fauna, ambient noise, and objects of historic or aesthetic significance (Cal. Code Regs., tit. 14, § 15382). Implementation of mitigation measures may or may not avoid the impact or reduce it to a less-than-significant level.

CEQA does not require mitigation for less-than-significant impacts.

PUBLICLY VISIBLE WATER VAPOR PLUMES

When a thermal power generation facility with a cooling tower[1] is operated at times when the ambient temperature is low and relative humidity is high, the warm moisture (water vapor) that is discharged from the cooling tower condenses as it mixes with cooler ambient air, resulting in creation of a visible plume. The publicly visible plume could substantially degrade the existing visual character or quality of the project site and its surroundings, potentially causing a significant impact to visual resources.

Computer modeling is used to estimate the frequency and size of the vapor plume(s) for a power plant project. If the plume modeling analysis results in a conclusion that plume frequency is greater than 20 percent, staff prepares an analysis of the vapor plume’s potential effects on visual resources in the VSOI for the project.

[1] Other types of thermal power generation facilities are also sources of visible water vapor plumes, including combined cycle gas turbine exhausts and geothermal steam exhausts. These facilities are evaluated in the same manner as cooling tower plumes.

Staff established a 20th percentile plume frequency during *seasonal* (November through April) *daylight clear* hours (i.e., no rain/fog high visual contrast hours) as a reasonable worst-case scenario. It is during high visual contrast viewing hours ("clear sky") conditions that water vapor plumes show the greatest contrast with the sky. Water vapor plumes emitted during rain and fog conditions and under some cloud conditions (e.g., marine layer) or at nighttime would not introduce substantial visual contrast into the environment. Staff has included in the *clear* category:

a) all hours with sky cover equal to or less than 10 percent, and

b) half of the hours with total sky cover of 20–90 percent.

The rationale for including these two components in this category is as follows:

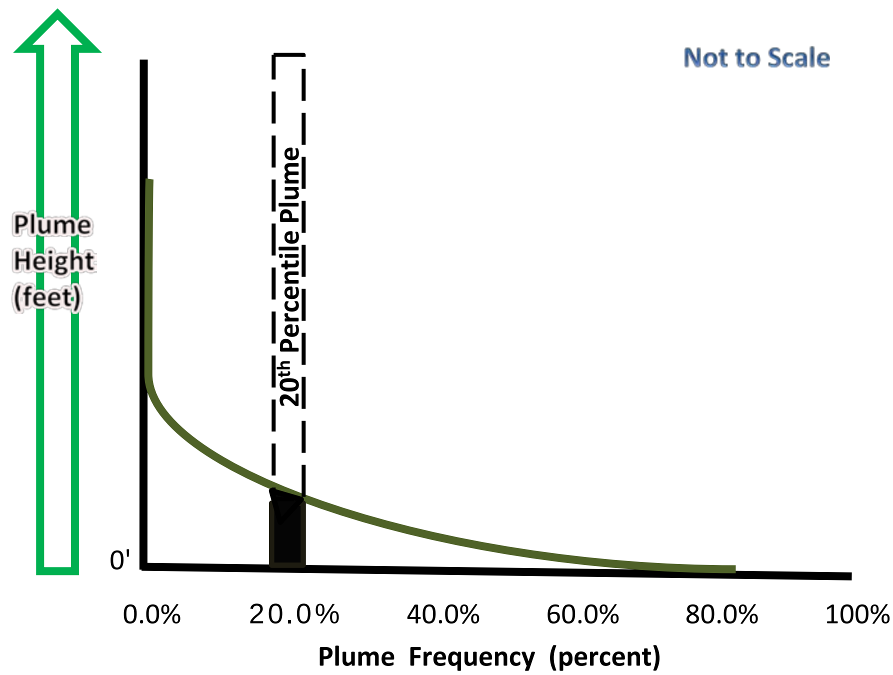
a) Visible plumes typically contrast most with sky under clear conditions, and when total sky cover is equal to or less than 10 percent, clouds either do not exist or they make up such a small proportion of the sky that conditions appear to be virtually clear.

b) For a substantial portion of the time when total sky cover is 20–90 percent, the opacity of sky cover is relatively low (equal to or less than 50 percent), so this sky cover does not always substantially reduce contrast with visible plumes; staff has estimated that approximately half of the hours meeting the latter sky cover criteria can be considered high visual contrast hours and are included in the "clear sky" definition.

Plume frequency is calculated on the six-month portion of the year when the ambient conditions are such that visible water vapor plumes are most likely to occur. This maximum six-month "seasonal" period for plume formation generally occurs between November and April when temperatures are cool or cold, and relative humidity is high.

Staff uses the Combustion Stack Visible Plume (CSVP) model to estimate plume frequency and plume size. If the CSVP modeling conducted for the proposed project's cooling tower predicts a *seasonal daylight clear* hour plume frequency of 20 percent or greater, staff evaluates the *20th percentile plume* in the visual resources analysis. (Discussions of visible water vapor plumes are presented in the Visual Resources section of staff assessments.) Staff considers the 20th percentile plume to be the reasonable worst-case plume dimension for the purpose of analysis. Publicly visible plumes that occur more than 20 percent of the time would be more frequent but smaller in size than those that occur less than 20 percent of the time. This approach recognizes that the largest plumes would occur very rarely, while the most frequent plumes and even the average plumes would be much smaller in size. For example, using a scale of 0 to 100, a one percentile plume would be extremely large, very noticeable to a wide area, but would occur very infrequently. A 100th percentile plume would be nonexistent (see Diagram 2 below). If the modeled publicly visible plume is predicted to occur less than 20 percent of seasonal daylight clear hours, the impact to the existing visual character or quality of the project site and its surroundings is generally considered less than significant, and it is not considered further in the visual resources analysis.

Visual Resources Diagram 2 – Visible Plume Height/Frequency Curve



A plume frequency of 20% represents staff's threshold for conducting a detailed plume analysis.

In the evaluation of the visual effects of the modeled 20th percentile plume, staff addresses the *overall visual sensitivity* for the existing condition and the potential *overall visual change* created by the plume's degree of contrast, level of dominance, and view blockage from the selected KOPs (see Visual Resources Diagram 1).

PUBLICLY VISIBLE WATER VAPOR PLUME ABATEMENT METHODS

Staff has identified four methods to lower a plume's frequency or eliminate the plume completely.

Increase Cooling Tower Air Flow

Increasing the cooling tower air flow will lower the exhaust temperature and reduce plume frequency but would not eliminate the potential for visible water vapor plumes under all conditions. This method focuses on the design of the cooling tower fan flow capacity versus the amount of heat rejected in the cooling tower. Any specific cooling tower design needs to be fully modeled to determine the effective final plume frequency reductions.

Wet/Dry Cooling Tower

This type of cooling tower reduces plume formation by adding heat or heated ambient air to the saturated wet cooling section exhaust to reduce its saturation level. The saturated exhaust can be heated using a separate dry module above the wet cooling tower. Alternatively, outside air can be pulled into separate areas where a dry section heats the air to reduce humidity and a wet section creates warm, humid exhaust. The heated ambient air and humid exhaust are mixed to reduce the humidity of the combined exhaust steam to avoid creating a plume when meeting ambient air.

The amount of plume reduction that can be accomplished by this type of system can vary from a relatively moderate reduction to a significant reduction in visible plume frequency. The specific wet/dry design would be based on the desired degree of plume reduction.

Wet Surface Air Cooler

The basic operating principle of a wet surface air cooler (WSAC) is rejection of heat by evaporation. The WSAC technology is similar to a wet/dry cooling tower. Where this system is different is that it could eliminate the need for a heat exchanger. The cooling fluid(s) used for the intercooler and any auxiliary cooling systems could be piped directly into the WSAC, which can operate as a non-contact heat rejection system with the use of water sprayed over the cooling pipes to increase the heat rejection when necessary. The expected hot temperature of the cooling fluid would increase the efficiency of this type of system. There may still be the potential for plumes to form under high cooling load periods during certain ambient conditions, but the WSAC could be designed, such as for wet/dry operation depending on cooling load, to maintain a minimal plume frequency well below 20 percent during “clear hours.”

Air Cooled Condenser (Dry Cooling)

The use of an air cooled condenser (ACC) would eliminate the formation of a publicly visible water vapor plume. Air cooled condensers condense exhaust steam from the steam turbine and return condensate to the boiler to perform this function. Steam enters the air cooled condenser above the heat exchangers, flows downward through the heat exchanger tubes, where it condenses and is captured in pipes at the base of the heat exchangers. The condensate is then returned to the boiler water system. Mechanical fans force air over the heat exchangers.

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VISUAL RESOURCES APPENDIX-2

Visual Resources Appendix-2 – Key Observation Point Evaluation Matrix and Visual Impact Determination Conclusions												
KOP	**Visual Sensitivity (Existing Condition)**							**Visual Change (Proposed Condition)**				**Visual Impact Determination**
			Viewer Exposure									
	Visual Quality	**Viewer Concern**	**Visibility**	**Number of Viewers**	**Duration of View**	**Overall Viewer Exposure[1]**	**Overall Visual Sensitivity[2]**	**Contrast**	**Dominance**	**View Blockage**	**Overall Visual Change[3]**	**Overall Visual Sensitivity + Overall Visual Change[4]**
1 – View from Channel View Park / Long Beach Bikeway Route 10	Low	High	Low	High	Moderate to High	Moderate	Moderate	Low	Low	Low	Low (None)	Less Than Significant
2 – View from University Park Estates	Low	High	Low	High	Moderate to High	Moderate	Moderate	Low	Low	Low	Low	Less Than Significant
3 – View from Marine Stadium Park	Moderate	High	Low	High	Moderate	Moderate	Moderate to High	Low	Low	Low	Low	Less Than Significant
4 – View from Loynes Drive	Low	Low	High	Low	Low	Low to Moderate	Low	Moderate	High	High	Moderate to High	Less Than Significant

Notes: High = 5 Moderate to High = 4 Moderate = 3 Low to Moderate = 2 Low = 1

[1] Visibility + Number of Viewers + Duration of View ÷ 3 = Overall Viewer Exposure
[2] Visual Quality + Viewer Concern + Overall Viewer Exposure ÷ 3 = Overall Visual Sensitivity
[3] Contrast + Dominance + View Blockage ÷ 3 = Overall Visual Change
[4] Overall Visual Sensitivity + Overall Visual Change = Visual Impact Determination (see Table 5 in Appendix VR-1)

VISUAL RESOURCES

Testimony of John Hope

SUMMARY OF CONCLUSIONS

The proposed Alamitos Energy Center (AEC) project would be constructed at the site of the existing Alamitos Generating Station (AGS). Critical off-site viewpoints, referred to as key observation points (KOPs), were selected to represent primary viewer groups and sensitive viewing locations in a defined area surrounding the project site where visual impacts could occur. California Energy Commission staff did not identify significant visual resources impacts at three of the four KOPs used in the analysis for the AEC and visual impacts at these KOPs are considered less than significant. Impacts at KOP 3 are considered less than significant with mitigation incorporated (Condition of Certification **VIS-2**).

Staff evaluated the potential effects of the long-term schedule for the proposed construction of the AEC. Staff concludes that construction and commissioning activities would not substantially degrade the existing visual character and quality of the site and its surroundings. In addition, staff analyzed the potential for lighting of the project site and structures during construction, commissioning, and operation to create new sources of substantial light or glare. Staff proposes Conditions of Certification **VIS-1, VIS-2**, and **VIS-4** to reduce potential effects of lighting and glare on nighttime and daytime views to less than significant.

A portion of the project site is in the state's Coastal Zone. Section 30251 of the California Coastal Act requires that the scenic and visual qualities of coastal areas be considered and protected as resources of public importance. Permitted development must be sited and designed to restore and enhance visual quality in visually degraded areas where feasible. The applicant has indicated that a landscape design plan would be prepared for the AEC prior to commencement of construction. The plan would provide details as to how the project owner intends to enhance visual quality at the project site. Staff proposes Condition of Certification **VIS-3** to require preparation of landscaping plans prior to project implementation to satisfy the requirements of the city of Long Beach's South East Area Development and Improvement Plan (SEADIP) Specific Plan, the certified local coastal program for this area of the state.

INTRODUCTION

Visual resources are the natural and cultural features of the environment that can be viewed. Visual resources also include "sensitive viewing areas," which are areas consisting of uses such as residential, recreational, travel routes, and tourist destinations, and the people within those use areas, or "sensitive viewers." This analysis focuses on whether the AEC would cause significant adverse visual impacts and whether the project would be in compliance with applicable laws, ordinances, regulations and standards (LORS). The California Environmental Quality Act (CEQA) requires the California Energy Commission to determine the potential for significant impacts to visual resources resulting from the proposed project.

Visual Resources Appendix-1 (VR Appendix-1), Visual Resources Terms, Definitions, and Analysis Method, describes the visual resources methodology employed for the CEQA analysis (Energy Commission staff's methodology), and the "Method and Threshold for Determining Significance" subsection below describes the thresholds for determining environmental consequences. In accordance with staff's procedure, conditions of certification are proposed as needed to reduce potentially significant impacts (under CEQA) to less than significant levels or to the extent possible, and to ensure LORS conformance, if feasible.

This section describes existing visual resources conditions in the vicinity of the proposed AEC and assesses changes to those conditions that would occur from construction and operation of the proposed project.

Staff visited the project site in October 2013 and surveyed existing visual resources in the project area. The descriptions of visual resources in this analysis are based on staff's direct observations, proposed project materials and data prepared by the applicant and submitted to the Energy Commission in October 2015, and other information and planning documents addressing visual resource conditions and issues in the project area.

LAWS, ORDINANCES, REGULATIONS, AND STANDARDS

LORS pertaining to aesthetics and protection of sensitive visual resources are summarized below. Further details on applicable LORS and analyses of the proposed project's consistency with specific policies and ordinances are discussed below under "Compliance with Laws, Ordinances, Regulations, and Standards." No federal LORS pertaining to visual resources are applicable to the proposed AEC.

STATE

California Coastal Act of 1976

The California Coastal Commission (Coastal Commission) was established by voter initiative in 1972 and later made permanent by the California State Legislature through adoption of the California Coastal Act of 1976 (Coastal Act) (Pub. Resources Code § 30000 et seq.). The Coastal Act includes policies addressing many environmental and land use management issues and defines the Coastal Zone boundary where those policies apply. Section 30001.5 of the Coastal Act includes a declaration to "protect, maintain, and where feasible, enhance and restore the overall quality of the coastal zone environment and its natural and artificial resources." Section 30251 of the Coastal Act requires that the scenic and visual qualities of coastal areas be considered and protected as resources of public importance.

Implementation of Coastal Act policies is accomplished primarily through preparation of local coastal programs (LCPs) by local municipalities that are located wholly or partly in the Coastal Zone. The city of Long Beach is a shoreline community, a portion of which is in the state's Coastal Zone. Coastal Act policies are the standards by which the Coastal Commission evaluates the adequacy of an LCP. An LCP includes a land use plan (LUP), which may be the relevant portion of the local general plan, including any maps necessary to administer the plan; and zoning ordinances, zoning district maps, and other legal instruments necessary to implement the LUP (Coastal Commission 2016).

The city of Long Beach's LCP was prepared to implement the Coastal Act, to "supplement and enhance" the Coastal Act, and to protect and enhance the city's Coastal Zone and its resources (City of Long Beach 1980, I-2 – I-3). The LCP was certified by the Coastal Commission in 1980 (City of Long Beach 2016a).

LOCAL

City of Long Beach General Plan

Applicable goals, objectives, and policies in the Long Beach General Plan include those pertaining to visual and aesthetic resources in general, development in areas designated as Mixed Use, and development in the Coastal Zone. The city prepared the Local Coastal Program of its General Plan to guide development for its portion of the Coastal Zone. The General Plan Open Space and Recreation Element, Air Quality Element, Land Use Element, and Conservation Element also contain goals, objectives, and policies that are potentially applicable to the proposed project.

South East Area Development and Improvement Plan (SEADIP)

The SEADIP includes provisions pertaining to visual and character quality of development from public views and surrounding development, along with landscaping requirements.

City of Long Beach Municipal Code Zoning Ordinance

The purpose of the city's zoning ordinance is to regulate land use development within the city of Long Beach in conformance with the general plan. Chapter 21.37 (Planned Development Districts) includes the SEADIP Specific Plan (PD-1), which implements the policies of the city's certified LCP. In addition, Chapter 21.42 contains development and design standards that are applicable to landscaped areas.

SETTING

PROJECT AREA CHARACTERISTICS

The project area is characterized by flat, sea-level topography built with urban mixed uses (e.g., industrial, commercial, residential) and pockets of maritime land uses including the San Gabriel River, Los Cerritos Channel, marina, open spaces, wetlands, and marina-oriented commercial businesses.

The existing AGS is situated on a flat coastal plain with a site elevation of approximately 10 to 20 feet above mean sea level (msl). The project site is located between the San Gabriel River and Los Cerritos Channel. The ridgeline of the hills beyond San Pedro to the northwest and the Santa Ana Mountains to the southeast are visible in background views from the project area. Roughly the southern half of the existing AGS site is located within the coastal zone and the northern half of the site is located outside of the Coastal Zone. A portion of the proposed AEC Power Block 1 and the construction access road would be constructed within the Coastal Zone.

The AEC would be located in an area of existing energy facilities that is surrounded by residential neighborhoods, open spaces, commercial developments, transportation corridors, and a marina and harbor area. The area on the north side of the AEC site includes the Southern California Edison (SCE) 230-kilovolt (kV) switchyard. The Plains West Coast Terminals Tank Farm encompasses the area on the south side of the AEC site.

The San Gabriel River Bike Trail parallels both banks of the San Gabriel River and is adjacent to the AEC site. The Los Angeles Department of Water and Power (LADWP) Haynes Generating Station occupies a large site on the east side of the San Gabriel River and east of the AEC site. Immediately beyond the LADWP generating facility is the senior residential community known as Leisure World.

PROJECT SITE CHARACTERISTICS

The existing AGS site would be used for construction and operation of the proposed AEC. The six AGS exhaust stacks, over 200 feet tall, and the generating units behind the stacks, are approximately 750 feet from the nearest residential neighborhood (University Park Estates located west across the Los Cerritos Channel). Compared to other development in the surrounding area, including the relatively low-profile tank farm, the AGS, SCE switchyard transmission structures, and LADWP generating facility are the most visually prominent, built features in the project area.

The northwest corner of the existing AGS site, adjacent to the main entrance, is landscaped with trees and shrubs. The main entrance to the AGS is from North Studebaker Road. Views toward the AEC site from the north, west, and south are partially limited because of tree and shrub landscaping along adjacent roadways (i.e., Studebaker Road, Westminster Avenue, Highway 22).

The applicant describes existing lighting of the AGS structures as being equipped with red flashing aviation safety lights on the top of the existing exhaust stacks and exposed stairways and scaffolding are illuminated with bright, unshielded bulbs (AES 2015, 5.13-14).

The existing AGS generates steam to produce electricity, and the technology and operational characteristics produce visually prominent water vapor plumes from the exhaust stacks. Based on staff's review of photographs of the power plant, a visible plume emanates from the exhaust stack in varying weather conditions. Water vapor plumes form more frequently and are most visible during daytime hours in the winter when the sky is relatively clear. Highly visible water vapor plumes from the existing power plant slightly increase the industrial character and appearance of the site.

ASSESSMENT OF IMPACTS AND DISCUSSION OF MITIGATION

METHODS AND THRESHOLDS FOR DETERMINING SIGNIFICANCE

CEQA provides a series of broad policy statements addressing environmental protection, including the requirement to: "Take all action necessary to provide the people of this state with clean air and water, enjoyment of *aesthetic, natural, scenic*, [emphasis added] and historic environmental qualities..." (Pub. Resources Code § 21001 [b]).

Staff uses the environmental checklist in the "Aesthetics" section of Appendix G of the CEQA Guidelines and professional practices for visual resource assessments to evaluate the potential effects of a project on visual resources. From the State CEQA Guidelines, an impact on visual resources is considered significant if the project would:

1. Have a substantial adverse effect on a scenic vista;
2. Substantially damage scenic resources, including but not limited to trees, rock outcroppings, and historic buildings within a state scenic highway;
3. Substantially degrade the existing visual character or quality of the site and its surroundings, or;
4. Create a new source of substantial light or glare that would adversely affect daytime or nighttime views in the area.

The CEQA Guidelines define a significant effect on the environment to mean a substantial, or potentially substantial, adverse change in any of the physical conditions within the area affected by the project, including land, air, water, minerals, flora, fauna, ambient noise, and objects of historic or aesthetic significance" (Cal. Code Regs., tit.14, § 15382). The section, "Direct and Indirect Impacts and Mitigation Measures," (below) includes a complete analysis of impacts from the proposed project.

Vista can be defined as a distant view through or along an avenue or opening. For this visual resources analysis, the definition of a scenic vista is expanded to include views that include remarkable or memorable scenery or views of a natural or cultural feature that is indigenous to the area. The proposed AEC would be constructed in a mostly developed area of Southern California. Views in the vicinity of the existing AGS primarily include built elements typical of urban development in similar urbanized areas. No particular view in the project vicinity has a level of scenic appeal that could distinguish it as a scenic vista. Because the AEC would have no impact on a scenic vista, no further analysis of the project relating to this criterion is necessary.

There are no scenic resources on the AEC site that could be damaged by the proposed project. The Pacific Coast Highway (PCH) (State Route 1) extends approximately ½-mile to the southwest of the AEC site and is part of a much longer segment of the highway extending north and south of the site. Segments of the PCH in Ventura, Los Angeles, and Orange counties are on the list of eligible state scenic highways, as shown on the California Scenic Highway Program website (California Department of Transportation 2016); however, the PCH is not an officially designated state scenic highway in the region. No further analysis of the project relating to this criterion is necessary.

The analysis below is focused on Appendix G questions 3 and 4.

Analysis Method

The method for this assessment of impacts on visual resources is primarily adapted from guidelines used by the U.S. Forest Service, U.S. Bureau of Land Management, and U.S. Department of Transportation. These guidelines are useful and meaningful for assessing the potential impacts of projects in various environmental settings, including the setting for the proposed AEC.

The process to evaluate potential impacts on visual resources from construction and operation of the AEC involved these general steps:

- Define the visual environment, or visual sphere of influence (VSOI), within which visual impacts could occur. As stated in the Application for Certification (AFC), the VSOI may be refined based on computer viewshed analysis and mapping.
- Describe sensitive viewpoints and the process to select key observation points, or critical viewpoints, within the VSOI for the project.
- Evaluate the potential effects of the project on visual resources based on the estimated visual sensitivity of the viewing public, the probability that the project site and area would demonstrate a noticeable visual impact with project implementation, and the estimated magnitude of the visual change that would occur with project construction and operation.
- Evaluate whether the proposed project would comply with applicable LORS for protection of visual and aesthetic resources.

Visual Resources Appendix-1 (Appendix VR-1) of this staff assessment, **Visual Resources Terms, Definitions, and Analysis Method**, provides further detail on the approach and process used in this visual resources analysis.

Visual Sphere of Influence

The VSOI for the proposed AEC takes into account the estimated visibility of its most visible structures on the project site, existing development in the area, and other variables potentially affecting visibility of the site. The highest level of visibility exists when the viewer is stationary and has direct and close-up views of the site (e.g., nearby residents). A lower level of visibility exists, for example, when the viewer is farther from the site (e.g., residents that are approximately a mile or more from the site) and/or are traveling on local roadways not immediately adjacent to the site.

The limits of the VSOI for the project generally extend to encompass the furthest distance at which potentially significant visual impacts could occur. For views of the AEC, this distance was determined by staff to be approximately 1½ miles. At greater distances, the mass of project structures in the views would be much less dominant compared to views at closer distances.

Process to Select Key Observation Points

Sensitive Viewing Areas and Identification of Key Observation Points

The visual analysis for the proposed AEC involved identifying key observation points (KOPs), or critical viewpoints that would most clearly show the visual effects of the proposed project. Results of the VSOI analysis and photographic survey for the AEC resulted in selection of four critical viewpoints to represent views from areas with relatively high levels of visual sensitivity. KOPs were selected to represent viewing conditions from nearby residential neighborhoods and recreation areas. Visual Resources (VR) Figure 1 shows the results of the viewshed analysis and the KOPs for the proposed project. **VR Figure 2** shows further detail for the project area. The four KOPs selected for this analysis are:

KOP 1 – View from Channel View Park / Long Beach Bikeway Route 10

KOP 2 – View from University Park Estates

KOP 3 – View from Marine Stadium Park

KOP 4 – View from Loynes Drive

Major AEC Components

The proposed project components would be located entirely on the existing AGS 63-acre site; no off-site linear elements are proposed. The project would include a new, single-circuit, on-site 230-kV transmission line to interconnect the proposed power blocks to the existing SCE 230-kV switchyard adjacent to the north. VR Table 1 summarizes the dimensions and quantities of the project components on the AEC site that would likely be visible to the public from offsite locations.

Visual Resources Table 1
Visually Prominent Proposed AEC Structures

Project Feature	Length (feet)	Width (feet)	Height (feet)	Diameter (feet)	Color	Materials	Finish
Combined-Cycle Power Block 1							
Administration Building	100	50	25	---	Tan		Flat / Untextured
Water Treatment Building	75	70	20	---	Tan	Ribbed Sheet Steel	Flat / Untextured
Warehouse Building	100	60	25	---	Tan	Ribbed Sheet Steel	Flat / Untextured
Gas Compressor Building	100	62	25	---	Tan	Ribbed Sheet Steel	Flat / Untextured
Air Cooled Condenser	299	211	104	---	Gray	A-36 Steel Shapes	Flat / Untextured
Demin Water Storage Tank	---	---	25	28	Gray	A-36 Steel	Flat / Untextured
Steam Turbine and Generator (STG)	90	33	62	---	Gray	A-36 Steel Plate	Flat / Untextured
STG Step-Up Transformer	28	16	25	---	Gray	Mid Steel Plate	Flat / Untextured
Combustion Turbine	56	25	29	---	Gray	Steel	Flat / Untextured
Combustion Turbine Generator (CTG)	37	18	28	---	Gray	Steel	Flat / Untextured
Air Inlet Filter	45	25	40	---	Gray	Custom Steel Shape	Flat / Untextured
Fuel Gas Filter/Separator	11	11	22	18	Gray	Custom Steel Shape	Flat / Untextured
Generator Breaker	19	15	28	---	Gray	Mid Steel Plate	Flat / Untextured
CTG Step-Up Transformer	30	23	25	---	Gray	Custom Steel Shape	Flat / Untextured
Heat recovery steam generator (HRSG)	139	57	95	38	Gray	A-36 Steel Plate	Flat / Untextured
Stack	---	---	140	20	Gray	A-36 Steel Plate	Flat / Untextured
Blowdown Tank	---	---	20	9	Gray	A-36 Steel	Flat / Untextured
Auxiliary Boiler and Associated Equipment	40	41	38	---	Gray	Ribbed Sheet Steel	Flat / Untextured

Project Feature	Length (feet)	Width (feet)	Height (feet)	Diameter (feet)	Color	Materials	Finish
Air Cooled Heat Exchanger	81	56	35	---	Gray	Mild Steel Plate	Flat / Untextured
Waste Water Tank	---	---	25	28	Gray	A-36 Steel	Flat / Untextured
Condensate Tank	---	---	25	28	Gray	A-36 Steel	Flat / Untextured
Transformer Wall	50	40	28	---	Untinted	Concrete	Flat / Untextured
Acoustical Barrier	262	182	35	---	Untinted	Concrete	Flat / Untextured
Single-Cycle Power Block 2							
Fin Fan Cooler	151	130	32	---	Gray	A-36 Steel Shapes	Flat / Untextured
Site Fence	---	---	7	---	Gray	Steel	Flat / Untextured
Combustion Turbine	60	20	15	---	Gray	Steel	Flat / Untextured
Combustion Turbine Generator	28	22	28	---	Gray	Steel	Flat / Untextured
Air Inlet Filter	48	35	14	---	Gray	Custom Steel Shape	Flat / Untextured
Fuel Gas Compressors	42	27	18	---	Gray	Ribbed Sheet Steel	Flat / Untextured
Intercooler Skid	50	31	14	---	Gray	Structural Steel Shape	Flat / Untextured
Stack	---	---	80	13.5	Gray	A-36 Steel Plate	Flat / Untextured
Selective Catalytic Reduction (SCR) Unit	37	23	38	---	Gray	Mid Steel Plate	Flat / Untextured
Combustion Turbine VBV Silencer Stack	---	---	48	11	Gray	A-36 Steel Plate	Flat / Untextured

Source: AES 2015, pp. 5.13-10 - 5.13-11

Steps in the KOP Analysis

The evaluation of the visual sensitivity for each representative KOP includes consideration of five factors: visual quality, viewer concern, visibility, number of viewers, and duration of view (see Diagram 1 in APPENDIX VR-1). Overall viewer exposure for each KOP is generally based on an average of the values for site visibility, number of viewers, and duration of view. Overall visual sensitivity is generally based on an average of the values for visual quality, viewer concern, and overall viewer exposure. APPENDIX VR-1 includes definitions for the key terms used in this analysis.

The assessment of visual impacts by staff is based on the change that would occur from the introduction of new built elements in the VSOI. The *overall visual change* is typically based on an average of the values for *contrast, dominance,* and *view blockage* for each KOP. The rating scale to assess visual sensitivity and visual change ranges from low to high for each factor. **Visual Resources Appendix-2 (VR Appendix-2), Key Observation Point Evaluation Matrix and Visual Impact Determination Conclusions,** describes the rating scale and summarizes the evaluations for each KOP's existing and proposed condition and the visual impact determination conclusion of the proposed project at each KOP. The ratings for *overall visual sensitivity* and *overall visual change* are combined to determine the visual impact significance for each KOP using **VR Appendix-1, Table 5 – KOP Visual Impact Significance Determination**).

Visual Sensitivity for the KOPs

The discussion above under, "Steps in the KOP Analysis," summarizes the process to determine impact significance. APPENDIX VR-1 describes key terms and the method used by staff to evaluate effects of a project on visual resources.

KOP 1 – View from Channel View Park / Long Beach Bikeway Route 10 (Existing Condition)

Channel View Park extends along the Los Cerritos Channel adjacent to the University Estates residential neighborhood. The park encompasses 5.28 acres of land and incorporates a portion of the Long Beach bikeway between Loynes Drive and 7th Street. Kettering Elementary School is located adjacent to the northern extent of the park. KOP 1 is located within the park at the end of 5^{th} Street across the Los Cerritos Channel.

Visual Resources Figure 3a shows the existing view from KOP 1 looking southeast toward the project site. Channelized water in the Los Cerritos Channel along with its rock bed and scrub brush along the top of the banks are visible in the foreground. Trees adjacent to Studebaker Road and on the western edge of the AGS site, along with utility lines, create the middle ground and screen the lower levels of the AGS structures and screen distant views beyond the site. The six existing AGS stacks and scaffolding-covered boiler are skylined above the treetops. Traffic traveling along Studebaker Road is also in the view.

The existing AGS power plant is composed of immense, complex, mechanical structures in an area where the built environment is generally characterized by low buildings (e.g., residences, commercial businesses) and relatively open views of the nearby residential and recreational uses. There is little or no visual coherence or harmony in the southeastward view from KOP 1 and from other nearby viewpoints from Channel View Park. The AGS power plant is a visually discordant built element in the view and visual quality for KOP 1 is characterized as low.

Viewers at KOP 1 include recreationists engaged in passive and active recreational activities in Channel View Park and/or Long Beach Bikeway. Viewers near KOP 1 include persons walking, bicycling, and jogging on the bikeway that parallels the Los Cerritos Channel along with people picnicking in the park. Other viewer groups near KOP 1 include students at Kettering Elementary School located at the northern extent of Channel View Park. Viewer concern for visitors to Channel View Park and Long Beach Bikeway and other viewpoints near KOP 1 is considered high.

Under existing conditions, the lower portions of the AGS power plant structures are screened, but given their height and bulk, views of the AGS from KOP 1 are mostly unimpeded. As a result, the AGS power plant structures block the views of the proposed AEC site. Therefore, visibility of the AEC project site at this location is low.

The city of Long Beach classifies Channel View Park as a greenway park which is a largely undeveloped green space, often a remnant or odd shaped piece of land left over from development, which can be used for casual recreation uses. The city does not provide an estimate as to the number of users of a greenway park; therefore, staff presumes that the number of recreational users per day averages over 200 and that the number of viewers for KOP 1 is high (see Table 2 in **Appendix VR-1**). The duration of view for KOP 1 varies depending on the visitor's type of activity and whether a recreational activity is active (e.g., bicycling, jogging) or passive (e.g., walking, picnicking). Duration of view for KOP 1 is considered high or moderate to high.

Based on the ratings for visibility, number of viewers, and duration of view, overall viewer exposure for KOP 1 is considered moderate.

Due to the dominance of the AGS in views from KOP 1, visual quality is characterized as low. Viewer concern is characterized as high. Based on the ratings for visual quality, viewer concern, and overall viewer exposure, overall visual sensitivity for KOP 1 is considered *moderate*.

KOP 2 – View from University Park Estates (Existing Condition)

University Park Estates, located to the west across the Los Cerritos Channel, is the closest residential neighborhood to the AEC site. The neighborhood is located between 7th Street and Loynes Drive and is adjacent to Channel View Park and Long Beach Bikeway Route 10. KOP 2 is located within the neighborhood at the intersection of Silvera Street and Eliot Street.

Visual Resources Figure 4a shows the existing view from KOP 2 looking east toward the AEC site. Hardscape of the street and front yard landscaping dominate the foreground view. Trees and utility lines located at the end of Eliot Street and in Channel View Park create the middle ground and screen the lower levels of the AGS and screen distant views beyond the AEC site. Six existing AGS stacks and a scaffolding-covered boiler are skylined above the treetops. Multiple vapor plumes may occasionally be seen by residents from the multiple stacks during weather conditions conducive to plume formation, further emphasizing the industrial character of development within close proximity to the residential subdivision.

The existing AGS encompasses immense, complex, mechanical structures in an area where the built environment is generally characterized by low buildings (e.g., residences, commercial businesses) and relatively open views of the nearby residential and recreational uses. There is little or no visual coherence or harmony in the eastward view from KOP 2 and from other nearby viewpoints from University Park Estates. The AGS is a visually discordant built element in the view and visual quality for KOP 2 is characterized as low.

Viewers at KOP 2 include motorists and residents engaged in active and passive recreational activities. Viewers near KOP 2 include people driving a vehicle or bicycling on the street and people walking or jogging on sidewalks. Other viewer groups near KOP 2 include people relaxing in their front or backyard. Viewer concern for residents in University Park Estates and other viewpoints near KOP 2 is considered high.

Under existing conditions, the lower portions of the AGS structures are screened by trees in Channel View Park, but given the height and bulk of the power plant structures, views of the AGS from KOP 2 are mostly unimpeded. As a result, the AGS power plant structures block the views of the proposed AEC site. Therefore, visibility of the project site at this location is low.

Staff presumes that the number of users per day averages over 200 and that the number of viewers for KOP 2 is high (see Table 2 in **Appendix VR-1**). The duration of view for KOP 2 varies depending on the visitor's type of activity and whether a recreational activity is active (e.g., driving, jogging) or passive (e.g., walking, sitting). Duration of view for KOP 2 is considered high or moderate to high.

Based on the ratings for visibility, number of viewers, and duration of view, overall viewer exposure for KOP 2 is considered moderate to high.

Due to the dominance of the AGS in views from KOP 2, visual quality is characterized as low. Viewer concern is characterized as high. Based on the ratings for visual quality, viewer concern, and overall viewer exposure, overall visual sensitivity for KOP 2 is considered *moderate*.

KOP 3 – View from Marine Stadium Park (Existing Condition)

Marine Stadium Park is located at the confluence of the Los Cerritos Channel and Alamitos Bay (Marine Stadium portion). Marine Stadium is popular location for rowing, water skiing, and speedboats. KOP 3 is located within the park at the intersection of Appian Way and Bay Shore Avenue adjacent to Marine Stadium (**VR Figure 5a**, existing view).

Visual Resources Figure 5a shows the existing view from KOP 3 looking northeast toward the AEC site. Channelized water in the Alamitos Bay, along with buoys, dominates the foreground. Docked boats, trees, and various developments (e.g., residential, recreation, commercial) adjacent to the waterline create the middle ground. The AGS is viewable in distant background down the Los Cerritos Channel. Six stacks of the existing AGS are skylined above the waterline.

The existing AGS power plant is composed of immense, complex, mechanical structures in an area where the built environment is generally characterized by low buildings (e.g., residences, commercial businesses) and relatively open views of the nearby residential and recreational uses. The physical boundaries of the Los Cerritos Channel create a visual coherence and harmony in the northeastward view from KOP 3 and from other nearby viewpoints from Marine Stadium. The AGS power plant is not a visually discordant built element in the view because of the distance between the observation point and the site. Visual quality for KOP 3 is characterized as moderate.

Viewers at KOP 3 include recreationists engaged in passive and active recreational activities in Alamitos Bay and/or Stadium Park. Viewers near KOP 3 include people recreating on the water in Alamitos Bay and Los Cerritos Channel. Other viewer groups near KOP 3 include residents along the waterfront. Viewer concern for visitors to Marine Stadium and other viewpoints near KOP 3 is considered high.

Under existing conditions, the AGS power plant structures are not screened from KOP 3. Although the height and bulk of the power plant structures are substantial and views of the AGS from KOP 3 are mostly unimpeded, the viewing distance to the power plant reduces the scale of the power plant structures to blend with development in the middle ground along the waterfront. Therefore, visibility of the project site at this location is considered low.

The city of Long Beach classifies Marine Stadium Park as a special use park which provides unique cultural heritage and/or educational features which attract a broad audience from near and far. The city does not provide an estimate as to the number of users of a special use park; however, Marine Stadium Park is public boat launch and the city identifies it as one of the world's premier water skiing facilities. Staff presumes that the number of recreational users per day averages over 200 and that the number of viewers for KOP 3 is high (see Table 2 in **Appendix VR-1**). The duration of view for KOP 3 varies depending on the visitor’s type of water activity (e.g., paddling, water skiing). Duration of view for KOP 3 is considered moderate.

Based on the ratings for visibility, number of viewers, and duration of view, overall viewer exposure for KOP 3 is considered moderate.

Due to the AGS not being a dominant visual element from KOP 3, visual quality is characterized as moderate. Viewer concern is characterized as high. Based on the ratings for visual quality, viewer concern, and overall viewer exposure, overall visual sensitivity for KOP 3 is considered *moderate to high*.

KOP 4 – View from Loynes Drive (Existing Condition)

Loynes Drive traverses in an east-west direction to the west of the project site. Loynes Drive deadends at Studebaker Road, which extends adjacent to the western boundary of the project site. Motorists traveling east along Loynes Drive have a direct, unobstructed view of the project site. KOP 4 is located on the bridge crossing over the Los Cerritos Channel within ¼ mile of the western edge of the project site.

Visual Resources Figure 6a shows the existing view from KOP 4 looking east toward the AEC site. The roadway surface and bridge components are visible in the foreground. Structures of the existing AGS and a storage tank dominate the middle ground view. Structures at the LADWP Haynes Generating Station can be seen in the background and blend in with the existing industrial structures at the AGS. Overall, the middle ground and background views are dominated by the prominence of the existing AGS and LADWP power plant structures.

The existing AGS power plant is composed of immense, complex, mechanical structures including whitewashed stacks and boilers with exposed scaffolding which add distinct elements to the viewpoint. The combination of vertical and horizontal forms creates little or no visual coherence or harmony in the eastward view from KOP 4. The human-made electrical generation facilities are visually discordant built elements in the view and visual quality for KOP 4 is characterized as low.

Viewers at KOP 4 primarily include motorists with the occasional pedestrian and bicyclist. Viewers near KOP 4 include primarily persons driving but also include those walking and bicycling. Viewer concern for viewers at KOP 4 is considered low.

Under existing conditions, the AGS power plant structures are not screened and fully portray their height and bulk. Overall, views of the AGS power plant from KOP 4 are unimpeded. Visibility of the project site at this location is very high.

Staff presumes that the number of recreational users per day averages less than 200 and that the number of viewers for KOP 4 is low (see Table 2 in **Appendix VR-1**). The duration of view for KOP 4 varies depending on the visitor's type of activity and whether a recreational activity is active (e.g., bicycling, jogging) or passive (e.g., walking, picnicking). Visitors to KOP 4 would primarily involve an active activity because there are no passive recreational facilities available at KOP 4. Duration of view for KOP 4 is considered low.

Based on the ratings for visibility, number of viewers, and duration of view, overall viewer exposure for KOP 4 is considered low to moderate.

Due to the dominance of the AGS in views from KOP 4, visual quality is characterized as low. Viewer concern is characterized as low. Based on the ratings for visual quality, viewer concern, and overall viewer exposure, overall visual sensitivity for KOP 1 is considered *low*.

DIRECT AND INDIRECT IMPACTS AND MITIGATION MEASURES

This assessment of impacts on visual resources addresses impacts that would occur from construction and operation of the power plant components at the AEC site. Due to the multi-year construction periods for the proposed project, impacts on visual resources from construction activities are considered to be long term rather than temporary.

Section 5.13.4 of the AFC, "Mitigation Measures," states that the proposed project "…would result in an overall visual quality which would remain the same. Because there will be no significant adverse visual impacts, given the existing conditions and the design features discussed [in the AFC], no additional mitigation measures are required" (AES 2015, pp. 5.13-17). Section 5.13.2.5 of the AFC, "Impact Significance," states that with implementation of the proposed project"… there will be no change in the views from KOPs 1 and 3, there will be a very minor and clearly less than significant change to the view from KOP 2, and there will be a slight positive change to the visual quality of the view from KOP 4" (AES 2015, pp. 5.13-16).

Staff's analysis under, "Visual Change for the KOPs," evaluates the visual resources impacts on sensitive viewer groups. The proposed project's potential to comply with applicable LORS is discussed below under, "Compliance with Laws, Ordinances, Regulations, and Standards."

Visual Change for the KOPs

The discussion above under, "Steps in the KOP Analysis," summarizes the process to determine impact significance. APPENDIX VR-2 shows the KOP evaluation matrix summarizing the process to determine the visual impact conclusions described below.

KOP 1 – View from Channel View Park / Long Beach Bikeway Route 10 (Proposed Condition)

The visual simulation for KOP 1 shows the AEC as it would appear at the end of construction activities for a viewer at Channel View Park across the Los Cerritos Channel from the project site (**VR Figure 3b**, simulated view).

As shown in the simulated view, the collection of AGS structures, tanks, and stacks viewable beyond the tree line would remain. The new stacks as part of the AEC would be lower than the existing AGS stacks and the new heat recovery steam generator (HRSG) units would be smaller, sleeker units that would be hidden behind the tree line extending along the western perimeter of the project site. The scale and height of existing power plant structures would not change in the view. The proposed facility would be obstructed by the existing, intervening trees and infrastructure. The AEC would not be a dominant feature and would not disrupt any portion of the skyline at the tree line because the AEC stacks and HRSG units would not be visible features in the view from this location. With the implementation of the proposed AEC, the skyline would remain the same from this viewpoint.

The overall visual change is typically based on an average of the values for contrast, dominance, and view blockage. Although overall visual sensitivity for KOP 1 is considered moderate, the overall visual change as a result of the proposed AEC compared to existing conditions would be low (none). From this viewpoint, constructing new angular, metallic power plant structures would not change visual resource conditions to a notable or significant degree. Compared to existing conditions, implementation of the AEC would not change the existing visual character and quality of the site and its surroundings for views at or near KOP 1, and the impact is considered ***less than significant***.

KOP 2 – View from University Park Estates (Proposed Condition)

The visual simulation for KOP 2 shows the AEC as it would appear at the end of construction activities for a viewer at the intersection of Silvera Street and Eliot Street within the University Park Estates residential neighborhood (**VR Figure 4b**, simulated view).

As shown in the simulated view, the tall AGS stacks and boiler viewable beyond the neighborhood would remain. The new air-cooled condensers, HRSG units, and stacks would be shorter than existing structures, and would be mostly hidden behind the houses and vegetation in the foreground of the view. The overall scale and height of power plant structures in the view would not change. The proposed facility would be obstructed by the existing, intervening trees and residences and thereby would not change the contrast in the view nor change the overall dominance of power plant structures in the view. To the extent that they are visible, the air-cooled condensers, HRSG units, and stacks would create a solid line of developed features that would appear through breaks in trees located in Channel View Park. However, views of these structures would not extend above the highest portion of the tree line.

The existing tall stacks and scaffold-covered structures, which are currently the most visually discordant elements in the backdrop of the view, would not be removed as part of the proposed project. However, it should be noted that the project owner intends to remove the existing AGS power plant structures under terms of a memorandum of understanding (MOU) with the city of Long Beach at a future date. The new AEC stacks and HRSG units would appear lower than the trees and in line with residential rooftops, creating the appearance of an intact skyline.

Although overall visual sensitivity for KOP 2 is considered moderate, the overall visual change as a result of the proposed AEC compared to existing conditions would be low. From this viewpoint, constructing new angular, metallic power plant structures would not change visual resource conditions to a notable or significant degree. Compared to existing conditions, implementation of the AEC would slightly change the existing visual character and quality of the site and its surroundings for views at or near KOP 2, and the impact is considered ***less than significant***.

KOP 3 – View from Marine Stadium Park (Proposed Condition)

The visual simulation for KOP 3 shows the AEC as it would appear at the end of construction activities for a viewer at Marine Stadium Park across Alamitos Bay and down the Los Cerritos Channel from the project site (**VR Figure 5b**, simulated view).

As shown in the simulated view, the existing assemblage of structures and stacks would not be removed as part of the proposed project. However, the project owner intends to remove the existing AGS power plant structures under terms of an MOU with the city of Long Beach at a future date. The new elements as part of the AEC would appear similar in scale to the existing AGS features.

Features of the AEC would appear equal in dominance with the existing AGS power plant structures in the open view across Alamitos Bay and up the Los Cerritos Channel. Similarly, the AEC structures would not change the contrast in the view because features of the AEC structures would not appear strikingly different from the existing AGS. The combination of the human-made features creates a visual mosaic with

various types, scales, colors, and forms. The AEC structures and stacks would increase the visual intactness of manmade structures across the horizontal plane. Structures of the AGS would continue to be silhouetted against the sky and viewable in the distance from Marine Stadium Park and nearby residences fronting the water. Construction of the proposed project would intensify the view of manmade structures in a continual horizontal pattern across the center view.

From this viewpoint, constructing new power blocks with angular, metallic power plant structures would change visual resource conditions to a noticeable degree. The overall visual change as a result of the proposed AEC compared to existing conditions would be moderate. Within the context of moderate to high visual sensitivity at KOP 3, this level of visual change compared to existing conditions would be considered a potentially significant impact. Implementation of staff's Condition of Certification **VIS-2** would minimize the potential for visual intrusion and reduce contrast by blending with the existing visual environment in the project area. ***Less than significant with mitigation incorporated***.

KOP 4 – View from Loynes Drive (Proposed Condition)

The visual simulation for KOP 4 shows the AEC as it would appear at the end of construction activities for a viewer on Loynes Drive at the bridge crossing over the Los Cerritos Channel (**VR Figure 6b**, simulated view).

As shown in the simulated view, the two stacks HRSG units, and the ACC associated with AEC Power Block 1, along with an assemblage of structures and stacks of the existing AGS, would be visible across the view. Two of the stacks in Power Block 2 are barely visible immediately to the left of the simulated Power Block 1 structures. The existing stacks and scaffolding at the LADWP Haynes Generating Station will remain partially visible in the view's background.

Features of the AEC would appear equal in dominance with the existing AGS power plant structures in the direct, unobstructed view from Loynes Drive. Similarly, the AEC structures would not change the contrast in the view because features of the AEC structures would not appear strikingly different from the existing AGS and Haynes power plants and the overall industrial nature of structures in the view. The combination of the human-made features creates a visual mosaic with various types, scales, colors, and forms. The AEC structures and stacks would increase the visual intactness of manmade structures across the horizontal plane. Structures of the AEC would be silhouetted against the sky similarly as the existing AGS structures. Construction of the AEC would intensify the view of manmade structures in the center view.

From this viewpoint, the new structures associated with the AEC would change visual resource conditions to a notable or considerable degree. Although the overall visual change would be moderate to high, within the context of the low visual sensitivity at KOP 4, the visual impacts of the AEC would be considered ***less than significant***.

Project Construction Visual Impacts

Construction Overview

The construction activities at the project site would occur on a single shift composed of a 10-hour workday, Monday through Friday, and a single 8-hour shift on Saturday. Construction would typically take place between the hours of 7:00 a.m. and 7:00 p.m., Monday through Friday, and 9:00 a.m. and 6:00 p.m. on Saturday. Overtime and additional shift work may be used to maintain the construction schedule or to complete critical construction activities (e.g., continuous pour and/or pouring concrete at night during hot weather, working around time-critical shutdowns and constraints).

The proposed project would require several areas for construction worker parking, storage, and laydown during site construction activities. Parking for workers would include an 8-acre area on the eastern and southern portions of the project site and a 10-acre area adjacent to the south of the project site. The adjacent 10-acre area is located along the west side of a rip rapped and channelized segment of the San Gabriel River that is flanked by industrial uses including the Los Angeles Department of Water and Power's Haynes Generating Station, decommissioned fuel oil tanks, high-voltage transmission lines, and the AGS. A segment of the San Gabriel River Bike Trail borders the east side of the river through this industrial area.

Existing vegetation and fencing would create a visual buffer and screening for views toward these open lots, which would presumably be full of vehicles during daylight hours and sometimes at night while construction progressed on the AEC.

Construction-Related Effects

The intensity of the long-term construction impact on visual resources would be greatest for sensitive viewer groups, primarily residents and recreationists, at the closest viewing distances to the project site. Construction activities would increase the presence and movement of heavy construction equipment and vehicles, large-scale construction work, and generation of dust over an approximately 5-year construction time frame at the project site. The long-term construction time frame could impact the ground surface on or adjacent to the project site from movement of heavy equipment and temporary storage of construction materials. Existing landscaped areas and the ground surface of areas at or near the AEC site would not be permanently impacted by the AEC. The construction parking and laydown areas are located in an existing disturbed area for utility uses. These areas are not located adjacent to public use areas. In addition, the AEC is located at or below the elevation of adjacent neighborhoods that surround the site which limits direct, unobstructed views of the construction areas. Neighborhoods located at an elevation above the AEC are located at a distance that substantially limits the ability of viewers to distinguish between construction equipment parked onsite and existing utility facilities.

The AEC is in an area with existing and former utility uses, and use of the 10-acre open lot at the AEC site for construction laydown would be a relatively minor change in visual resources conditions at this location. Long-term construction impacts at the AECP site would not substantially alter the visual character or quality of the site or surrounding area, and no impact on visual resources would occur.

Lighting and Glare Effects

Project Construction Lighting

Section 5.13.2.3.5 of the AFC, "Lighting," summarizes lighting requirements for night construction and commissioning activities. Although most construction activities would occur during daytime hours, additional hours could be necessary to make up schedule deficiencies or to complete critical construction activities (AES 2015, page 5.13-12). During some construction periods and the project commissioning/startup phase, work would continue 24 hours per day, 7 days per week. The frequency of nighttime work over the 5-year construction schedule is not known, and the applicant states that the project site could appear as a brightly lit area for limited times during project construction and commissioning. Although lighting of construction worker parking areas is not discussed in the AFC, staff assumes that security lighting of the construction parking areas would be necessary. The AFC states that nighttime construction and commissioning lighting would be shielded and directed toward the center of the construction activity. Task-specific lighting would be used to the extent practicable and in compliance with worker safety regulations. The AFC provides no further details (e.g., a process requiring the project owner to respond to a construction-related lighting complaint). In response to staff's data requests on construction lighting, the applicant states there is no expectation for placing lighting on tall structures (e.g., cranes) during construction activities unless required for safety (AES 2014).

Staff has incorporated the applicant's proposed measures into staff's recommended Condition of Certification **VIS-1**, which includes measures to minimize the potential impacts of long-term lighting for construction and commissioning work. Implementation of **VIS-1** would reduce lighting impacts during construction to ***less than significant***.

Project Operation Lighting

The AEC site is located in an urbanized area with existing street and industrial lighting. The amount of lighting in the area would increase marginally with the AEC. The AFC states that exterior lights for project operation would be hooded and directed onsite to minimize glare and light spillage beyond the project site (AES 2015, page 5.13-14). Low-pressure sodium lamps and/or efficient LED lighting with non-glare fixtures would be used for the project, and "switched lighting circuits" would be provided for areas not requiring continuous illumination. In addition, the AFC states the HRSG and air-cooled condenser structures would be lower than the existing boiler structures and their sides would be completely enclosed, without external scaffolding and stairways, thereby, requiring little to no need for external lighting. External lighting would be primarily restricted to the platforms on the tops of the HRSG structures. The applicant states that lighting fixtures would conform to standards (Dark Skies) for minimizing offsite lighting effects. Staff has incorporated the applicant's proposed measures into staff-recommended Condition of Certification **VIS-4** to ensure that operational lighting results in ***less than significant effects***. After the existing AGS generating units are retired (expected by the end of 2020), the AGS lighting needed for worker safety would no longer be required and would be turned off. At that time, the amount of lighting on the site, even with the lighting required by the AEC, would be less than at present.

Structure Surface Glare

The applicant has proposed no measures requiring surface treatments to minimize glare from project structure surfaces. The potential for glare from project structures to adversely affect daytime views in the project area is considered a potentially significant impact of the AEC. Condition of Certification **VIS-2** is proposed to require preparation and implementation of a Surface Treatment Plan to reduce the effects of glare from project surfaces to ***less than significant***.

Visible Plumes

When a thermal power generation facility is operated at times when the ambient temperature is low and relative humidity is high, the warm moisture (water vapor) in the exhaust plume condenses as it mixes with the cooler ambient air, resulting in formation of a visible plume[1]. This is similar to when the moisture-laden air in a person's breath on a cold day is chilled to the point where the water vapor condenses into lots of tiny droplets of liquid water, forming a visible cloudy fog. Formation of visible plumes typically occurs on cool, humid days when the outdoor air is at or near saturation[2].

Power plants like the proposed AEC produce high velocity, high temperature exhausts that disperse quickly, thereby, minimizing the probability that visible plumes would form above the stacks. Using data provided by the applicant, Energy Commission Air Quality staff conducted a preliminary assessment of the proposed project's exhaust gas plumes. Based on the AEC's exhaust gas characteristics and ambient air conditions, staff concluded that conditions would be unlikely to cause formation of visible plumes above the project's exhaust stacks. The AEC would not include wet cooling towers with evaporative cooling. Instead, the AEC would use dry cooling (i.e., ACCs) for heat rejection with no possibility of forming water vapor plumes. ***No impact*** on visual resources would occur pertaining to visible plumes.

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[1] Relative humidity is the percentage of the amount of water vapor in the air. The colder the air, the less water vapor it can carry.

[2] Saturated air is air containing the maximum amount of water vapor possible at a given temperature.

Cumulative Impacts

Section 15130 of the State CEQA Guidelines requires a discussion of cumulative impacts of a project when the project's incremental effect is cumulatively considerable. According to State CEQA Guidelines Section 15065(a)(3), "[c]umulatively considerable means that the incremental effects of an individual project are significant when viewed in connection with the effects of past projects, the effects of other current projects, and the effects of probable future projects." Sections 15130 and 15355 of the State CEQA Guidelines both stress cumulative impacts in the context of closely related projects and from projects causing related impacts. The goal of such an analysis is twofold: first, to determine whether the overall long-term impacts of all such projects would be cumulatively significant; and second, to determine whether the AEC itself would cause a "cumulatively considerable", and thus significant, incremental contribution to any such cumulatively significant impacts.

For this analysis, the impacts of cumulative projects (i.e., related projects) on visual resources are limited to those that could combine with the proposed project's visual resources impacts. The geographic scope of the area that could be subject to a cumulative visual effect is limited to the area very near the proposed AEC. Staff reviewed current and probable future projects occurring in the AEC area. Upon review of projects, staff determined that the distance between the AEC site and other current and probable future projects is of such distance to prevent a cumulative visual effect. In other words, an observer at any given location would be unable to see the AEC in combination with any current or probable future project. For this reason, the AEC would not contribute considerably to a cumulatively significant effect for visual resources.

Summary of Project Effects

As described above, criteria for determining the significance of impacts on visual resources are based on the environmental checklist form in Appendix G of the State CEQA Guidelines. This discussion summarizes the effects of the AEC on visual resources and the corresponding significance criteria for evaluating impacts on visual resources.

Substantial Adverse Effect on a Scenic Vista

Views in the vicinity of the AEC site include built elements typical of development in urbanized areas near the coast. No particular view in the project vicinity has a level of scenic appeal that could distinguish it as a scenic vista; therefore, the proposed project would have ***no impact*** relative to this criterion.

Substantially Damage Scenic Resources, Including But Not Limited to Trees, Rock Outcroppings, and Historic Buildings within a State Scenic Highway

Because the PCH is not an officially designated state scenic highway in the region, no impact would occur relative to this criterion. Furthermore, the project site does not contain scenic resources, including trees, rock outcroppings, and historic buildings; therefore, the proposed project would have ***no impact*** relative to this criterion.

Substantially Degrade the Existing Visual Character or Quality of the Site and its Surroundings

The visual character of the existing AGS site and adjacent areas are dominated by large-scale electric generation and transmission facilities that include the AGS, a large SCE substation and associated transmission lines, and the LADWP Haynes Generating Station and associated transmission lines. The visual character of views in the project vicinity would not substantially change overall because the AEC structures would add to an existing industrial visual environment which includes the AGS and LADWP power plant structures. From most KOPs, the proposed project would not substantially degrade the existing visual character of the project site and its surroundings and the proposed project would have a ***less than significant impact*** relative to this criterion. At KOP 3, visual impacts are considered ***less than significant with mitigation incorporated***.

Create a New Source of Substantial Light or Glare That Would Adversely Affect Daytime or Nighttime Views in the Area

The applicant has proposed measures to ensure that project lighting during construction, commissioning, and operation does not create significant visual impacts. Staff has incorporated these measures into Conditions of Certification **VIS-1** and **VIS-4** and concludes that the AEC would not create a new source of substantial light or glare that could adversely affect nighttime views in the area. ***Less than significant with mitigation incorporated.***

Implementation of staff's Condition of Certification **VIS-2** would minimize the potential for glint or glare from project structures to adversely affect daytime views in the project area. ***Less than significant with mitigation incorporated***.

COMPLIANCE WITH LORS

VR Table 2 summarizes LORS pertaining to protection of visual and aesthetic resources. The summary of applicable LORS in **VR Table 2** includes several that address minimizing the visual impacts of utilities by requiring landscape and architectural buffers and screens. The city's SEADIP Specific Plan includes Provision A2 which requires a minimum of thirty percent of the site shall be developed and maintained as usable open space. See applicable goals, objectives, and policies under, "South East Area Development and Improvement Plan (SEADIP) Specific Plan," in the table below.

Visual Resources Table 2
Proposed Project Consistency with Applicable Visual Resources LORS

Applicable LORS	Consistency Determination	Basis for Consistency
California Coastal Act of 1976		
Section 30251 Scenic and visual qualities. The scenic and visual qualities of coastal areas shall be considered and protected. Permitted development shall be visually compatible with the character of the area and, where feasible, to restore and enhance visual quality in visually degraded areas.	Refer to the analyses (below) under Provision A2 for the SEADIP Specific Plan.	
City of Long Beach General Plan		
Open Space and Recreation Element		
Policy 1.2 Protect and improve the community's natural resources, amenities and scenic values including nature centers, beaches, bluffs, wetlands and water bodies.	Consistency with Policy 1.2 to protect community natural resources, amenities, and scenic values is achieved with the project's proposed design.	The proposed arrangement of the AEC would locate components further away from surrounding areas (e.g., Los Cerritos Channel). The proposed lighting design (e.g., hooded lighting, lighting directed onsite) would minimize the potential for glare and light spillage into nearby recreation and open space areas.
Land Use Element		
Urban Design Analysis - Conclusions and Policy Directions Certain city entrances at arterial and freeways should be beautified to enhance the city's image. Of particular importance are the entrances at Seventh Street and Studebaker Road, and all the entrances from the Long Beach Freeway.	Consistency with Urban Design Analysis to beautify entrances along Studebaker Road is achieved with the project's proposed design.	The existing AEC has landscaping in place that complies with the requirements for setbacks, screening, and vegetation. The AEC site boundary does not reach to Studebaker Road and implementation of the AEC would not affect landscaping that is already in place along Studebaker Road. It should be noted that the city submitted a comment letter requesting all perimeter and public-facing landscape areas of the AGS be cleared and replanted with a comprehensively-designed landscape plan for the entire site (Long Beach 2016b). In addition, the applicant identified a commitment to work cooperatively with the city in submitting landscape plans for review and approval (AECP 2015, pg. 5.13-21). Implementation of Condition of Certification **VIS-3** would ensure conformance.

Applicable LORS	Consistency Determination	Basis for Consistency
Conservation Element		
Goals for the City No. 2 To create and maintain a productive harmony between man and his environment through conservation of natural resources and protection of significant areas having environment and aesthetic value.	Consistency with Goals for the city to protect significant areas with aesthetic value is achieved with the project's proposed design.	The proposed design for AEC would comply with all setback and buffer requirements. The applicant identified a commitment to work cooperatively with the city in submitting landscape plans for review and approval (AECP 2015, pg. 5.13-21). Implementation of Condition of Certification **VIS-3** would ensure conformance.
Local Coastal Program		
The LCP adopted the SEADIP Specific Plan by reference. Specific development and land use standards are provided within the SEADIP Specific Plan.	Refer to the analyses (below) under Provision A2 for the SEADIP Specific Plan.	
South East Area Development and Improvement Plan (SEADIP) Specific Plan		
Provision A2 A minimum of thirty percent of the site shall be developed and maintained as usable open space (building footprint, streets, parking areas and sidewalks adjacent to streets shall not be considered usable open space. Bicycle and pedestrian trails not included within the public right-of-way may be considered usable open space). All buildings shall be set back a minimum of twenty feet from all public streets and a wider setback may be required by individual subarea. Within this minimum twenty-foot setback area, a strip having a minimum width of ten feet and abutting the street shall be attractively landscaped.	Consistency with Provision A2 to identify open space areas on the AECP site would be achieved with implementation of **VIS-3**.	Condition of Certification **VIS-3** requires the project owner to provide landscaping that reduces the visibility of the power plant structures in accordance with local policies. In addition, the applicant identified a commitment to work cooperatively with the city in submitting landscape plans for review and approval (AECP 2015, pg. 5.13-21). Implementation of Condition of Certification **VIS-3** would ensure conformance.
Provision A9 All development shall be designed and constructed to be in harmony with the character and quality of surrounding development so as to create community unity within the entire area.	Consistency with Provision A9 to construct and design in harmony with the character and quality of surrounding development is achieved with the project's proposed design.	AEC would be designed to be in harmony with the industrial zone in which it is located. Condition of Certification **VIS-3** would ensure the AEC would comply with applicable development policies set forth in the General Plan and SEADIP.
Provision A12 Public views to water areas and public open spaces shall be maintained and enhanced to the maximum extent possible, consistent with the wetlands restoration plan.	Consistency with Provision A12 to maintain and enhance public views to water areas and public open spaces is achieved with the project's proposed design.	The AEC would not block views of water areas and public open spaces.

Applicable LORS	Consistency Determination	Basis for Consistency
City of Long Beach Municipal Code Zoning Ordinance		
21.42.010 Landscaping Standards ***Landscaping Purpose*** - Landscapes are intended to improve the physical appearance of the city by providing visual, ecological, and psychological relief in the urban environment. Successfully designed and maintained landscape areas provide an attractive living, working, and recreating environment in addition to their role in reducing water and energy consumption. ***General Requirement C*** - Plans Required. When applicable, a Landscape Document Package shall be approved prior to the issuance of any planning or building permit. For projects proposing landscape area coverage with a minimum of ninety percent (90%) very low to low water use plantings, ETWU and MAWA calculations are not required in the Landscape Document Package submittal. Applicable landscaping, irrigation, planter drainage, water reuse, retention and filtration improvements shall be implemented before any final building and planning inspection is approved.	Consistency with Municipal Code Section 21.42.010 to provide a Landscape Document Package would be achieved with implementation of **VIS-3**.	Condition of Certification **VIS-3** requires the project owner to provide a landscaping plan whose proper implementation would satisfy the Municipal Code requirements.
21.42.040 Landscaping standards for R-3, R-4 and Nonresidential Districts. ***Landscape Area Requirements.*** A. Applicability. All portions of a lot not paved or occupied by a structure shall be attractively landscaped. All required set back areas shall be landscaped unless used for a permitted use. B. Landscape Area Requirements On-Site Street Frontage - Within the required setback area along all street frontages, except at driveways, a minimum five-foot (5') wide landscaping strip (inside dimension to planter) shall be provided. This area shall be landscaped with one (1) tree for each fifteen (15) linear feet of street frontage and three (3) shrubs for each tree. Fences and retaining walls. All required fences and retaining walls shall be landscaped with vines planted no more than ten feet (10') on center on all accessible sides of a wall or alternative plant materials approved by the Director of Development Services.	Consistency with Municipal Code Section 21.42.040 to provide landscaped area along street frontages is achieved with the project's proposed design.	The AEC site boundary does not reach to Studebaker Road and implementation of the AEC would not affect landscaping that is already in place along Studebaker Road. It should be noted that the city submitted a comment letter requesting all perimeter and public-facing landscape areas of the AGS be cleared and replanted with a comprehensively-designed landscape plan for the entire site (Long Beach 2016b). In addition, the applicant identified a commitment to work cooperatively with the city in submitting landscape plans for review and approval (AECP 2015, pg. 5.13-21). Implementation of Condition of Certification **VIS-3** would ensure conformance.

RESPONSE TO COMMENTS ON THE PRELIMINARY STAFF ASSESSMENT

The applicant was the only entity to provide comments on the Preliminary Staff Assessment (PSA) related to visual resources (TN# 212487). No comments were received from the public, intervenors, or other agencies.

COMMENT:

The applicant identified inconsistencies in the text of the analysis.

Staff appreciates the applicant's identification of the inconsistencies and staff revised the text to make statements regarding KOP 3 and KOP 4 consistent.

COMMENT:

The applicant disagrees with staff's conclusions regarding the significance of visual impacts at KOP 3.

Response: Staff's conclusions on the significance of visual changes to the environment are primarily based on the visual sensitivity at each KOP. As indicated in the conclusion for KOP 3, the visual sensitivity is considered moderate to high. As indicated in the conclusion for KOP 4, the visual sensitivity is considered low. Even though the overall visual change is greater at KOP 4 as compared to KOP 3, the sensitivity of views from KOP 4 is considered lower as compared to KOP 3. Therefore, staff believes the conclusions made in the analysis regarding the significance of visual changes in the environment are supported by the evidence presented in the analysis. Specifically constructing new power blocks with angular, metallic power plant structures would change visual resource conditions from KOP 3 to a noticeable degree. The overall visual change as a result of the proposed AEC compared to existing conditions would be moderate. Staff does not agree with the Applicant's comment that the overall effect will be that the visual quality of the views from KOP 3 will remain the same.

Staff is aware of the Federal Highway Administration visual impact assessment methodology cited in the comment. Visual resource management guidelines and methods established by federal agencies, such as the visual management system of the U.S. Forest Service and the descriptions for distance zones used by the Federal Highway Administration, are adapted and used by staff to evaluate the impacts of a project on visual resources. Because the impacts to KOP 3 can be mitigated, staff reached the same conclusions as the applicant regarding the overall impacts to visual resources.

COMMENT:

*The applicant requested revisions to Conditions of Certification **VIS-1**, **VIS-2**, **VIS-3**, and **VIS-4**.*

> **Response:** Staff revised Conditions of Certification **VIS-1**, **VIS-2**, **VIS-3**, and **VIS-4** in response to the applicant's comments. The applicant's requested revisions involved identifying what would be included as part of the Lighting Management Plan and Surface Treatment Plan, along with clarifying the timeframe in which planting must occur. The applicant's requested revisions also included grammatical fixes.
>
> Lastly, the applicant requested removal of the language "of colorful, interesting, and distinctive character" from **VIS-3**. Staff agrees with this revision because this language is subjective even though this language was specifically requested to be included by the city of Long Beach (TN# 211372).

CONCLUSIONS AND RECOMMENDATIONS

Impacts on visual resources were assessed based on the magnitude of the anticipated incremental changes to the visual environment, considering the appropriate baseline conditions (i.e., existing conditions), and the estimated effects of those changes on sensitive viewer groups.

Lighting of the project site and structures during construction, commissioning, and operation could create new sources of substantial light or glare that could adversely affect daytime and nighttime views in the area. Staff proposes implementation of Conditions of Certification **VIS-1** and **VIS-4** to reduce the effects of lighting on visual resources. Condition of Certification **VIS-2** is proposed to require preparation and implementation of a Surface Treatment Plan to reduce the effects of daytime glare from project surfaces to less than significant. Lastly, staff proposes implementation of Condition of Certification **VIS-3** to require preparation of landscaping plans to satisfy the requirements of local policies.

With implementation of staff's proposed conditions of certification, the proposed project would not cause significant visual impacts and would comply with all applicable visual resources-related laws, ordinances, regulations, and standards.

PROPOSED CONDITIONS OF CERTIFICATION

VIS-1 **Lighting – Project Construction.** Consistent with applicable worker safety regulations, the project owner shall ensure that lighting of on-site construction areas and construction worker parking lots minimizes potential night lighting impacts by implementing the following measures:

- The Lighting Management Plan shall include three printed sets of full-size plans (24" x 36", minimum), three sets of 11" x 17" reductions, and a digital copy in PDF format, and contain the following information:
- All fixed-position lighting shall be hooded and shielded to direct light downward and toward the construction area to be illuminated to

prevent illumination of the night sky and minimize light trespass (i.e., direct light extending beyond the boundaries of the parking lots and construction sites, including any security-related boundaries).

- Lighting of any tall construction equipment (e.g., scaffolding, derrick cranes) shall be directed toward areas requiring illumination and shielded to the maximum extent practicable.
- Task-specific lighting shall be used to the maximum extent practicable.
- Wherever and whenever feasible, lighting shall be kept off when not in use and motion sensors shall be used to the maximum extent practicable.
- The Compliance Project Manager (CPM) shall be notified of any construction-related lighting complaints. Complaints shall be documented using a form in the format shown in Attachment 1, and completed forms shall record resolution of each complaint. A copy of each completed complaint form shall be provided to the CPM. Records of lighting complaints shall also be kept in the compliance file at the project site.

Verification: Within 7 calendar days after the first use of fixed-position parking area and construction lighting for major construction milestones, the project owner shall notify the CPM that the lighting is ready for inspection. Verification is to be repeated for these construction milestones:

- construction of Power Block 1
- construction of Power Block 2

If the CPM determines that modifications to the lighting are needed for any construction milestone, within 14 calendar days of receiving that notification, the project owner shall correct the lighting and notify the CPM that modifications have been completed.

Within 48 hours of receiving a lighting complaint for any construction activity, the project owner shall provide to the CPM a copy of the complaint report and resolution form, including a schedule for implementing corrective measures to resolve the complaint.

The project owner shall report any lighting complaints and document their resolution in the Monthly Compliance Report for the project, accompanied by copies of completed complaint report and resolution forms for that month.

VIS-2 **Surface Treatment of Project Structures and Buildings.** Prior to commercial operation of the Power Block 1, the project owner shall prepare and implement a Surface Treatment Plan addressing treatment of the surfaces of all project structures and buildings visible to the public such that proposed colors and finishes (1) minimize visual intrusion and reduce contrast by blending with the existing visual environment, (2) avoid creating new sources of substantial glint and glare, and (3) are consistent with all applicable laws, ordinances, regulations, and standards.

The Surface Treatment Plan shall include, at a minimum, the following elements:

- Description of the overall rationale for the proposed surface treatments, including selection of the proposed colors and finishes;
- Discussion of proposed opportunities and options for using color to enhance design quality;
- Schedule for completing the surface treatments;
- Procedure to ensure proper surface treatment maintenance for the life of the project;
- Three printed sets (11" x 17"), and a digital copy in PDF format of elevation drawings depicting ~~at life-size scale~~ the major project structures and buildings, keyed to a spreadsheet that for each structure and building specifies: (1) the proposed color and finish; and (2) the height, length, and width or diameter;
- Two sets of color brochures, color chips, and or physical samples showing each proposed color and finish. Digital files showing proposed colors may not be submitted in place of original samples. Colors must be identified by vendor, name, and number, or according to a universal designation system; and
- Three printed sets (11' x 17") and a digital copy in PDF format of color of a visual simulation at scale showing the surface treatment proposed for the project structures. The visual simulations for KOP 4 shall be used to prepare an image showing the proposed surface treatment plan.

The Surface Treatment Plan shall be submitted to the Compliance Project Manager (CPM) for review and approval. The project owner shall not submit instructions for colors and finishes to manufacturers or vendors of project structures, or perform final field treatment on any structures, until written approval of the final plan is received from the CPM. Modifications to the Surface Treatment Plan are prohibited without the CPM's approval.

Verification: At least 90 calendar days before submitting instructions for colors and other surface treatments to manufacturers or vendors of project structures, and/or ordering prefabricated project structures, the project owner shall submit the Surface Treatment Plan to the CPM for review and comment.

If the CPM determines that the plan requires revision, the project owner shall provide a plan with the specified revision(s) for review and approval by the CPM. No work to implement the Surface Treatment Plan shall begin until final plan approval is received from the CPM.

Prior to the start of commercial operation of Power Block 1, the project owner shall notify the CPM that surface treatments of all publicly visible structures and buildings identified in the Surface Treatment Plan have been completed and that the facilities are ready for inspection. The project owner shall obtain written confirmation from the CPM that the project complies with the Surface Treatment Plan.

VIS-3 **Perimeter Landscape Screening.** The project owner shall provide landscaping that provides minimum open space areas on the project site in accordance with local policies. The objective shall be to create landscape of a semi-permanent manner with California-native, drought-tolerant groundcover and tree species.

The project owner shall submit to the Compliance Project Manager (CPM) for review and approval and simultaneously to the city of Long Beach for review and comment a landscaping plan whose proper implementation will satisfy these requirements. The plan shall include:

a) A detailed landscape, grading, and irrigation plan, at a reasonable scale. The plan shall demonstrate how the requirements stated above shall be met. The plan shall provide a detailed installation schedule.

b) A list (prepared by a qualified professional arborist familiar with local growing conditions) of proposed species, specifying installation sizes, growth rates, expected time to maturity, expected size at five years and at maturity, spacing, number, availability, and a discussion of the suitability of the plants for the site conditions and mitigation objectives, with the objective of providing the widest possible range of species from which to choose;

c) Maintenance procedures, including any needed irrigation and a plan for routine annual or semi-annual debris removal for the life of the project; and

d) A procedure for monitoring for and replacement of unsuccessful plantings for the life of the project.

The plan shall not be implemented until the project owner receives final approval from the CPM.

Verification: The landscaping plan shall be submitted to the CPM for review and approval and simultaneously to the city of Long Beach for review and comment at least 90 days prior to installation.

If the CPM determines that the plan requires revision, the project owner shall provide to the CPM and simultaneously to the city of Long Beach a revised plan for review and approval by the CPM.

Planting must be completed or bonded by the start of commercial operation. Planting must occur during the optimal planting season, but not later than 12 months after the start of commercial operation. The project owner shall simultaneously notify the CPM and the city of Long Beach within seven days after completing installation of the landscaping that the landscaping is ready for inspection.

The project owner shall report landscape maintenance activities, including replacement of dead or dying vegetation, for the previous year of operation in each Annual Compliance Report.

Lighting Management Plan – Project Operation

VIS-4 The project owner shall prepare and implement a comprehensive Lighting Management Plan for project operations. The project owner shall not purchase or order any permanent lighting fixtures or apparatus until written approval of the final plan is received from the CPM. Modifications to the Lighting Management Plan are prohibited without the CPM's approval. Consistent with applicable worker safety regulations, the project owner shall design, install, and maintain all permanent exterior lighting such that light sources are not directly visible from areas beyond the project site, glare is avoided, and night lighting impacts are minimized or avoided to the maximum extent feasible. All lighting fixtures shall be selected to achieve high energy efficiency for the facility. The project owner shall meet these requirements for permanent project lighting:

1. The Lighting Management Plan shall include three printed sets of full-size plans (24" x 36", minimum), three sets of 11" x 17" reductions, a digital copy in PDF format.

2. The Lighting Management Plan shall be prepared with the direct involvement of a certified lighting professional trained to integrate efficient technologies and designs into lighting systems.

3. Exterior lights shall be hooded and shielded and directed downward or toward the area to be illuminated to prevent obtrusive spill light (i.e., light trespass) beyond the project site.

4. Exterior lighting shall be designed to minimize backscatter to the night sky to the maximum extent feasible.

5. Energy efficient lighting products and systems shall be used for all permanent new lighting installations. Smart bi-level exterior lighting using high efficiency directional LED fixtures shall be used as appropriate for exterior installations. The lighting system shall work in conjunction with occupancy sensors, photo sensors, wireless controls, and/or other scheduling or controls technologies to provide adequate light for security and maximize energy savings.

6. Lighting fixtures shall be kept in good working order and continuously maintained according to the original design standards.

7. The Lighting Management Plan shall be consistent with all applicable laws, ordinances, regulations, and standards.

The Compliance Project Manager (CPM) shall be notified of any complaints about permanent lighting at the project site. Complaints shall be documented using a form in the format shown in Attachment 1, and completed forms shall record resolution of each complaint. A copy of each completed complaint form shall be provided to the CPM. Records of lighting complaints shall also be kept in the compliance file at the project site.

Verification: At least 90 calendar days before installation of any permanent lighting equipment for the project, the project owner shall submit the comprehensive Lighting Management Plan to the CPM for review and approval.

If the CPM determines that the plan requires revision, the project owner shall provide a plan with the specified revision(s) for review and approval by the CPM. No work to implement the plan (e.g., installation of fixtures) shall begin until final plan approval is received from the CPM.

Prior to the start of commercial operation of the project, the project owner shall notify the CPM that installation of permanent lighting for the project has been completed and that the lighting is ready for inspection. If the CPM notifies the project owner that modifications to the lighting system are required, within 30 days of receiving that notification, the project owner shall implement all specified changes and notify the CPM that the modified lighting system(s) is ready for inspection.

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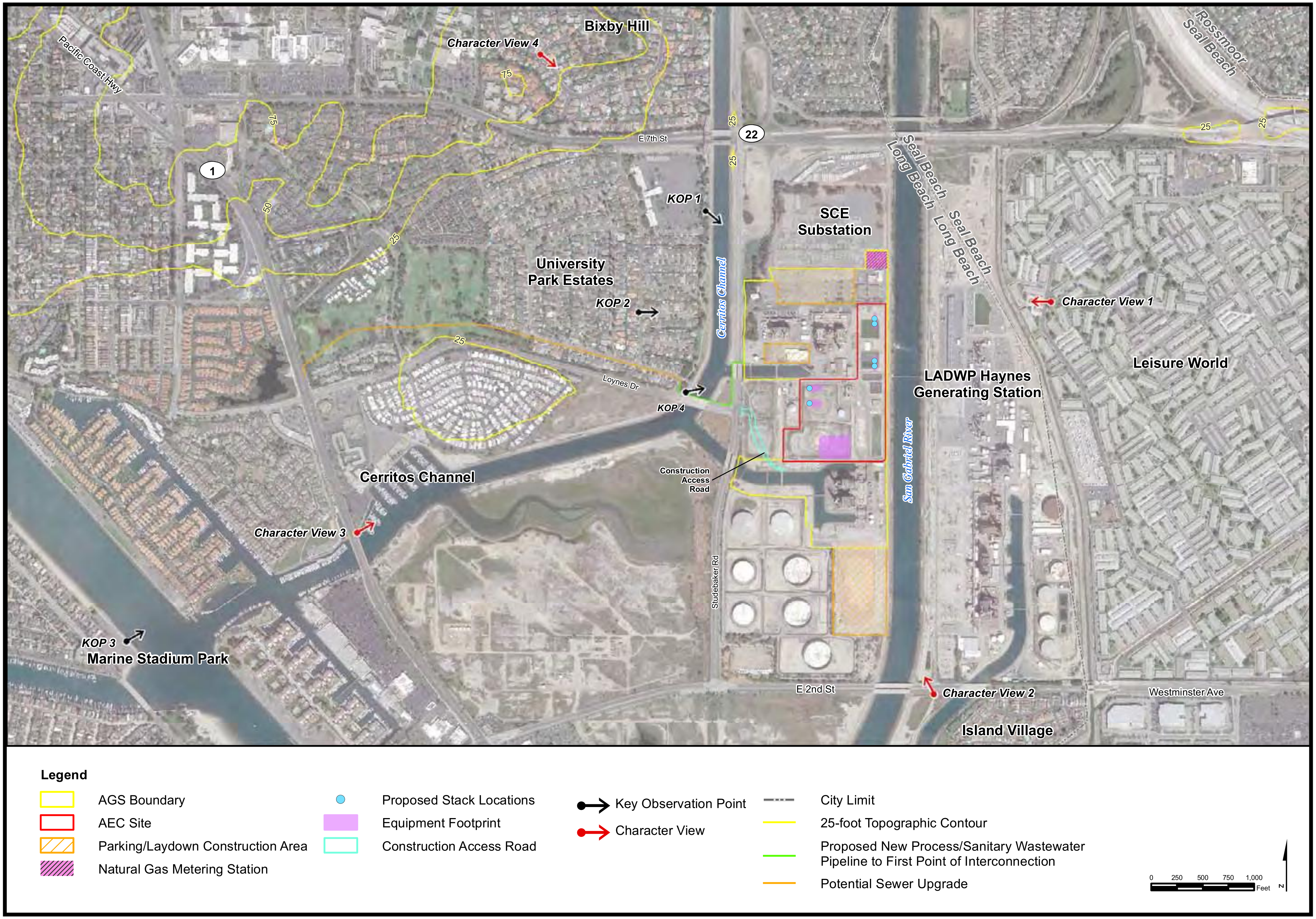
VISUAL RESOURCES - FIGURE 1

Alamitos Energy Center - Project Components, Key Observation Points and Character Views



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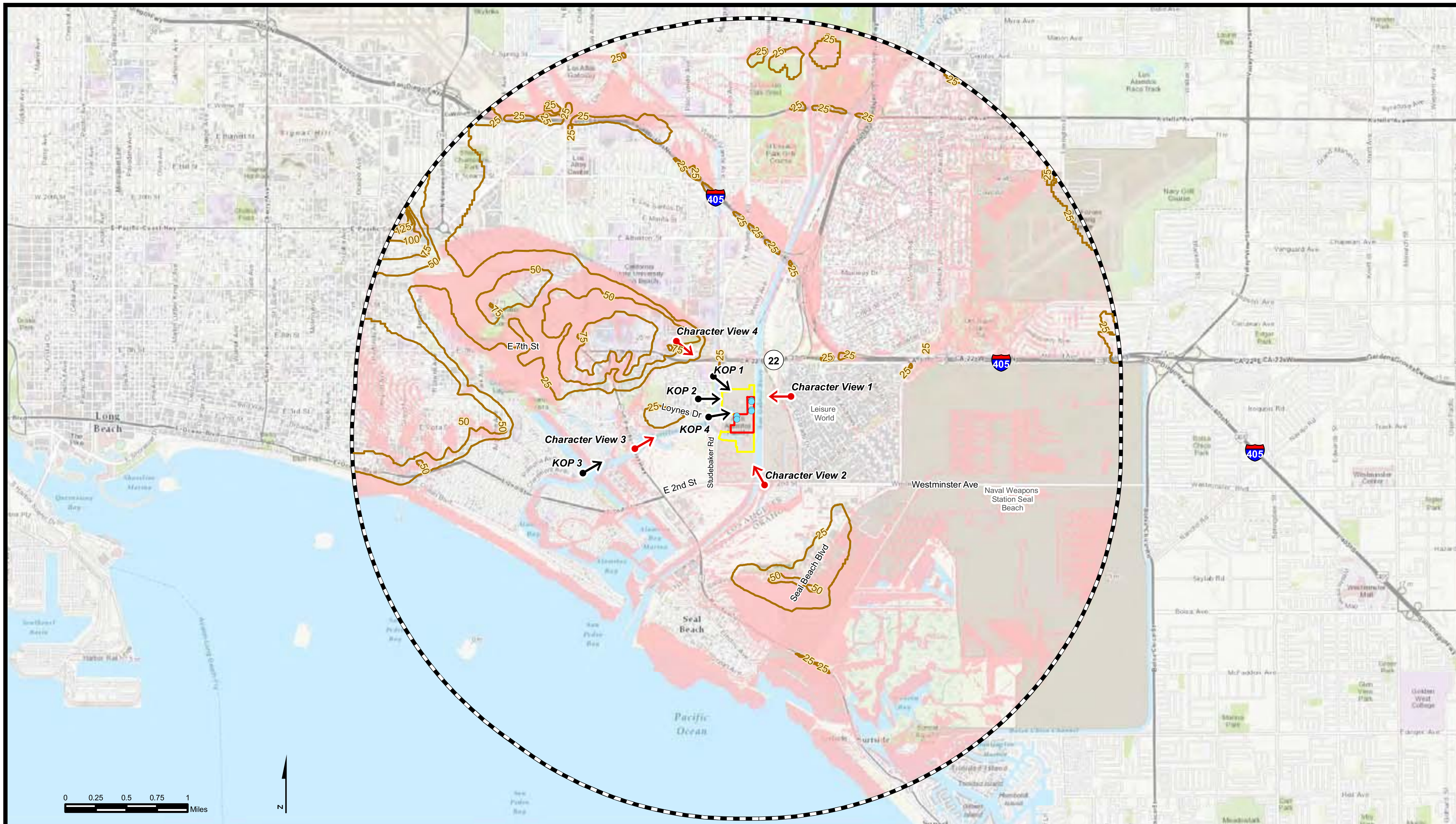
SOURCE: Supplemental AFC

VISUAL RESOURCES - FIGURE 2

Alamitos Energy Center - Project Viewshed, Key Observation Points and Character View Locations within 3 Miles of Project Site



Legend

- AGS Boundary
- AEC Site
- 25-foot Topographic Contour
- Potential Stack Locations
- Key Observation Point
- Character View
- 3- Mile Radius from Project Boundary

Potential Stack Visibility

- Areas within 3-mile radius from which the project will have the potential to be visible
- Areas within 3-mile radius from which the project will not be visible because the line of sight will be blocked by terrain

Notes:
Viewshed based on stack heights of 140 feet.
Elevation data from USGS 10 Meter DEM.

Service Layer Credits:
Esri World Topo Map

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SOURCE: Supplemental AFC

VISUAL RESOURCES - FIGURE 3a and b

Alamitos Energy Center - KOP-1 View from Channel View Park/Long Beach Bikeway Route 10

3a

KOP-1. Existing view toward the project site from Channel View Park and Long Beach Bikeway Route 10.

3b

KOP-1. Simulated view toward the project site after the addition of new AEC structures. New facilities will not be visible in this view.

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SOURCE: Supplemental AFC

VISUAL RESOURCES - FIGURE 4a and b

Alamitos Energy Center - KOP-2 View from University Park Estates

4a

KOP-2. Existing view toward the project site from a street in University Park Estates, the residential area closest to the project site. A boiler and stacks that are part of the ALamitos Generating Station that surround the project are visible extending above the trees in the background of the view.

4b

KOP-2. Simulated view toward the project site after the addition of new AEC structures. After the addition of AEC structures, two stacks will be partially visible in the right portion of the view.

CALIFORNIA ENERGY COMMISSION - SITING, TRANSMISSION AND ENVIRONMENTAL PROTECTION DIVISION

SOURCE: Supplemental AFC

VISUAL RESOURCES - FIGURE 5a and b

Alamitos Energy Center - KOP-3 View from Marine Stadium Park

5a

KOP-3. Existing view toward the project site from Marine Stadium Park. The Alamitos Generating Station that surrounds the project site is visible in the left half of the view as the two power units with the large, scaffold-covered boilers as well as the tops of two white appearing stacks in the center-right of the view which are partially obscured behind commercial development. The stacks and generating units that extend along the horizon in the right half of the view are all part of the LADWP Haynes Generating Station.

5b

KOP-3. Simulated view toward the project site after the addition of new AEC structures. The AEC structures will be visible in the distance at the far end of the channel in the center of the view.

CALIFORNIA ENERGY COMMISSION - SITING, TRANSMISSION AND ENVIRONMENTAL PROTECTION DIVISION

SOURCE: Supplemental AFC

VISUAL RESOURCES - FIGURE 6a and b

Alamitos Energy Center - KOP-4 View from Loynes Drive

6a

KOP-4. Existing view toward the project site from Loynes Drive

6b

KOP-4. Simulated view toward the project site after the addition of new AEC structures.

CALIFORNIA ENERGY COMMISSION - SITING, TRANSMISSION AND ENVIRONMENTAL PROTECTION DIVISION

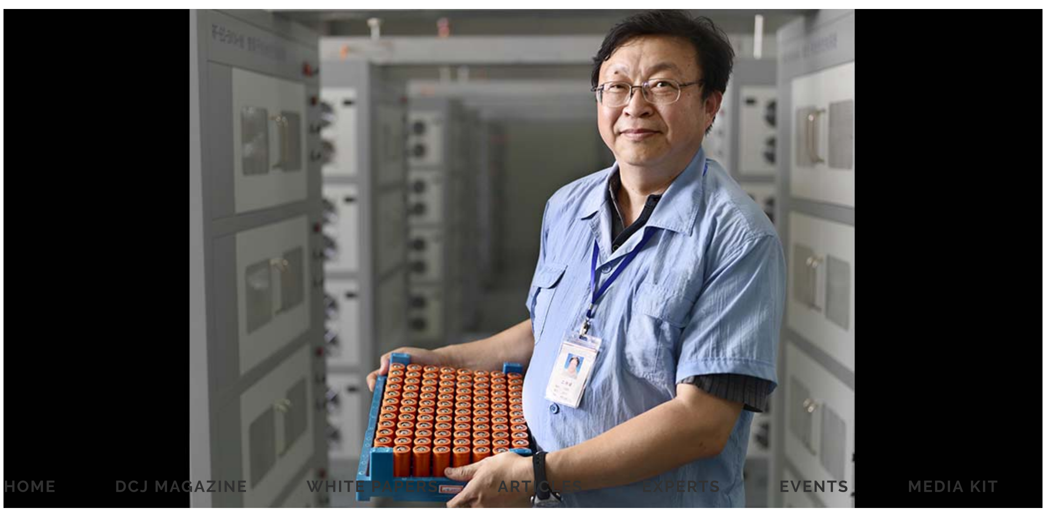
SOURCE: Supplemental AFC

DATACENTER Journal
Where IT, Facilities and Design Meet

FACILITIES

LITHIUM ION (LI-ION) BATTERIES: A FIRE POTENTIAL IN WAITING

written by Jonathan Ingram December 26, 2012



The proliferation of battery technologies in modern industry is presenting fire professionals with new sets of challenges. Confusion exists as to the correct approach for protecting industrial batteries from fire, including battery manufacturing, battery storage and battery-powered applications.

Lithium-ion (Li-ion) cells are distinctly different from lithium (primary) cells and are used in large numbers in power-grid stabilization systems, containerized battery systems and other large-scale applications. These types of systems have thousands to tens of thousands of these Li-ion cells integrated into a single space. The uses of Li-ion cells in these applications need to be reviewed for potential fire hazards, and fire protection strategies must be applied and implemented to reduce the risk.

Potential fire protection strategies include using gaseous fire-suppression agents, such as FM-200, 3M Novec 1230 fire protection fluid and/or Argonite to protect large arrays of Li-ion cells.

What You Should Know About Lithium-Ion Batteries

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Electrolytes used in Li-ion batteries are complex formulations composed of lithium salts such as $LiPF_6$, $LiBF_4$ or $LiClO_4$ in an organic solvent such as ethylene carbonate (EC), dimethyl carbonate (DMC), diethyl carbonate (DEC) or ethyl acetate (EA). A liquid electrolyte allows movement of lithium ions between the cathode and the anode when a battery passes an electric current through an external circuit

If overheated or overcharged, Li-ion batteries can suffer internal mechanical damage leading to electrical shorting and internal heating. Overheating and overcharging can also result in a thermal runaway event that can cause cell rupture and leakage of combustible electrolytes.

Electrolytes are Class B materials (flammable liquid), and the design concentration should be determined by test for the particular composition present.

Possible Gaseous Fire Extinguishing Solutions and Approaches

Rupture of Li-ion cells may result in the ejection of electrolyte, a Class B flammable or combustible liquid. Gaseous agents will extinguish flames produced by burning leaked electrolyte, but they have little or no capability to mitigate/prevent a thermal runaway occurring in Li-ion cells. These reactions are internal to the cell, and although the charging array will likely have preventative measures incorporated into their design, the reaction may still occur.

Despite the potential for Class B material discharge, two possible approaches remain to address the use of a gaseous fire-suppression agent for hazards involving Li-ion batteries.

1) On the basis of a risk assessment, hazard survey and customer/end-user strategy, the approach can be to protect the space solely according to the Class A materials present and/or the Class C energy source(s). This approach does not specifically protect against the Class B (electrolytic) material contained in the battery; this material would only be introduced into the hazard following a catastrophic failure of the battery cell itself.

2) On the basis of a risk assessment, hazard survey and customer/end-user strategy, the approach can be to protect the space according to the Class A materials present, the Class C energy source(s) and the Class B (electrolytic) material. This approach provides protection in the event that an ejection of the electrolyte material occurs—a material that could ignite when an ignition source is present.

Through cup-burner and other testing completed in accordance with the requirements and guidelines of NFPA 2001 (2012 Edition), Kidde Fire Systems has determined the minimum agent design concentration necessary to suppress a fire involving some of the most commonly used Class B compounds found in electrolytes. The table below lists the appropriate percentage by volume of agent needed to suppress a fire involving the most common types of materials found in Li-Ion batteries.

Materials	**Novec 1230 Fire Protection Fluid (FK-5-1-12)**	**FM-200 (HFC-227ea)**	**Argonite (IG-55)**
Ethyl Acetate	6.2% / V	8.9% / V	52.9% / V
Diethyl Carbonate	6.4% / V	8.5% / V	52.9% / V
Dimethyl Carbonate	6.3% / V	8.8% / V	52.9% / V
Ethyl Methyl Carbonate	6.6% / V	Data unavailable	52.9% / V

% / V = percentage by volume

Awareness of the growing use of Li-ion batteries in industrial and other large-scale applications requires an increasing awareness of the potential fire hazards posed by such batteries and the most effective fire protection systems to mitigate the risk.

About the Author

Jonathan Ingram is Director of Product Marketing for Kidde Fire Systems, part of UTC Climate, Controls & Security.

BATTERIES BATTERY DATA CENTER FIRE HAZARD FIRE SUPPRESSION LI-ION LITHIUM ION UPS

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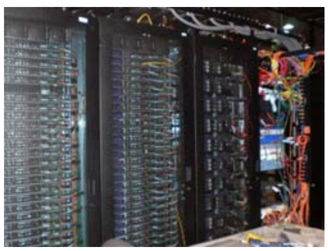

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Energy Storage Safety Strategic Plan

U.S. Department of Energy

Office of Electricity Delivery and Energy Reliability

December, 2014

Acknowledgements

The Department of Energy Office of Electricity Delivery and Energy Reliability would like to acknowledge those who participated in the 2014 DOE OE Workshop for Grid Energy Storage Safety (Appendix A), as well as the core team dedicated to developing this report to address the safety of grid energy storage systems: Sean J. Hearne, Summer Ferreira, Mark Smith, Abbas Akhil & Amanda Spinney (Sandia National Laboratories); Landis Kannberg, Vincent Sprenkle, & David Conover (Pacific Northwest National Laboratory); Matthew Paiss (International Association of Fire Fighters); Michael A. Stosser (Sutherland Asbill & Brennan LLP); Robert S. Fleishman (Morrison & Foerster LLP).

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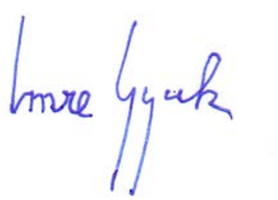

Dr. Imre Gyuk
Program Manager
Energy Storage Research
Office of Electricity Delivery and Energy Reliability
U.S. Dept. of Energy

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Executive Summary

Energy storage is emerging as an integral component to a resilient and efficient grid through a diverse array of potential application. The evolution of the grid that is currently underway will result in a greater need for services best provided by energy storage, including energy management, backup power, load leveling, frequency regulation, voltage support, and grid stabilization.[1] The increase in demand for specialized services will further drive energy storage research to produce systems with greater efficiency at a lower cost, which will lead to an influx of energy storage deployment across the country. To enable the success of these increased deployments of a wide variety of storage technologies, safety must be instilled within the energy storage community at every level and in a way that meets the need of every stakeholder.

In 2013, the U.S. Department of Energy released the Grid Energy Storage Strategy[2], which identified four challenges related to the widespread deployment of energy storage. The second of these challenges, the validation of energy storage safety and reliability, has recently garnered significant attention from the energy storage community at large.[3] This focus on safety must be immediately ensured to enable the success of the burgeoning energy storage industry, whereby community confidence that human life and property not be adversely affected is instilled from the earliest stages.[4] The resultant increase in consumer confidence in energy storage will ease and facilitate the expansion of energy storage's deployment, allowing for the electric grid to meet the ever-expanding needs of the consumer.

The safe application and use of energy storage technology knows no bounds. An energy storage system (ESS) will react to an external event, such as a seismic occurrence, regardless of its location in relation to the meter or the grid. Similarly, an incident triggered by an ESS, such as a fire, is 'blind' as to the location of the ESS in relation to the meter. This document will address grid-side safety, while recognizing that the efforts undertaken will apply to other ESS applications, regardless of deployment location.

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1 Grid Energy Storage Strategy. U.S. Department of Energy, Dec. 2013.

2 Grid Energy Storage Strategy. U.S. Department of Energy, Dec. 2013, p. 5.

3 DOE OE Energy Storage Safety Workshop, Albuquerque, NM. 2014.

4 Gyuk, Imre. "Energy Storage Safety: An Essential Concern." DOE OE Energy Storage Safety Workshop, Feb. 2014.

Each stakeholder group has a specific motivation for pursuing energy storage safety. Manufacturers are producing an increasing number of systems and system components to meet a growing demand for energy storage and must be confident in the safety of these products. Regulators are required to address the system installations in terms of application space, ownership, risk, and potential litigation. Insurers must develop applicable risk assessments and first responders must be able to safely and successfully respond to any incidents.

The actions, responsibilities, and concerns of each stakeholder group are all interconnected. The science-based techniques used to validate the safety of energy storage systems must be documented a relevant way, that includes every level of the system and every type of system. These science-based safety validation techniques will be used by each stakeholder group to ensure the safety of each new energy storage system deployed onto the grid. Once researchers establish science-based validation and mitigation techniques, manufacturers will have guidelines that support the construction of systems that can be validated as safe. With standardized guidelines for safe component and system construction, regulators and insurance companies will be able to fully assess the risk of owning and insuring each system. Additionally, first responders must be included in the discussion to ensure that all areas of potential failure are identified and the best mitigation strategies are developed, spanning the chemistries and materials choices through components, module layouts and deployment.

Safety of any new technology can be broadly viewed as having three intimately-linked components: 1) a system must be engineered and validated to the highest level of safety possible; 2) techniques and processes must be developed for responding to incidences if they do occur; and 3) the best practices and system requirements must then be reflected standardized safety determinations in the form of codes, standards and regulations (CSR) so that there is uniform, written guidance for the community to follow when designing, building, testing and deploying the system. When successful, CSRs apply the best-known practices for safety to a system. The predictability of real-time operation, and therefore safety, is improved when systems are designed with similar system requirements.

A thread of complexity running through all three of the components of safety (i.e. validation techniques, incident response and safety documentation) is an ever increasingly diverse portfolio of technologies and the wide array of potential deployment environments. To provide the greatest impact, the validation techniques discussion presented in this document focuses primarily on batteries, with some discussion of flywheels, as these two technologies are undergoing rapid evolution and growth in the deployment.

Safety documentation provides guidance to the energy storage community in the form of codes, standards, and regulations. Two crucial considerations must be taken into account surrounding the adoption and administration of standards. First, system owners must understand which codes and standards are necessary before and after the installation of energy storage systems. Second, the parties responsible for the oversight, regulation and response must be identified. This identification will ensure a clear path of communication between owners, regulators and responders to best prevent any potential incident. Both of these considerations will make the installation process efficient and cost effective for owners, ensure that all responsible parties are communicating to best avoid an incident, and ensure effective incident response. They will also clearly outline risk, which will enable the application of effective risk mitigation and risk management measures. These safety documents will be informed by the science-based validation techniques established through research and development. This work will provide the basis for the protocols and design in the codes and standards and will meet the needs to minimize loss and protect the first responders.

The goal of this DOE Office of Electricity Delivery and Energy Reliability (OE) Strategic Plan for Energy Storage Safety is to develop a high-level roadmap to enable the safe deployment energy storage by identifying the current state and desired future state of energy storage safety. To that end, three interconnected areas are discussed within this document:

Science-based Safety Validation Techniques:

- Most of the current validation techniques that have been developed to address energy storage safety concerns have been motivated by the electric vehicle community, and are primarily focused on Li-ion chemistry and derived via empirical testing of systems. Additionally, techniques for Pb-acid batteries have been established, but must be revised to incorporate chemistry changes within the new technologies. Moving forward, all validation techniques must be expanded to encompass grid-scale energy storage systems, be relevant to the internal chemistries of each new storage system and have technical bases rooted in a fundamental-scientific understanding of the mechanistic responses of the materials. Experimental research and development efforts to inform models from cell to system scale must be the basis of the next generation of validation techniques needed for the new grid-scale storage systems, as empirically derived tests are not sufficient to ensure safety.

Incident Preparedness:

- First responders will be called upon to respond to an incident should it occur to protect the lives of anyone involved and minimize the damage to assists. Therefore, there must be a deliberate and concerted effort to engage the first responder community early in the design and siting of energy storage systems so that proper mitigation techniques can be developed and systems designed to improve the overall safety and ability to quickly and safety resolve the incident. This must include the development of techniques to extinguish any fires if they were to occur and respond to the variety of non-fire incidents that may require fire department response, developing site specific training for first responders, improved systems design, and the development of incident response plans. All of these must be based on the scientific understanding of the systems, materials and processes and embodied in the criteria in codes, standards and regulations.

Safety Documentation:

- Currently, safety-related criteria in the form of codes, standards and regulations that apply to system components and deployments need to be updated to reflect the growing verity of storage technologies. This documentation is not specific to the multitude of chemistries and assembled modules that compose the new storage systems being deployed. As a result, CSR are inefficient and ineffective and must be updated and standardized.

This document additionally highlights four key elements around which DOE efforts will revolve.

DOE programmatic efforts will focus on four elements:

- ESS safety technology
- Risk assessment and management
- Incident response

- Codes, standards and regulations

To ensure the thorough establishment of the scientific and technical basis for ESS safety in each technology, information concerning all safety hazards must be gathered and categorized. Testing and analysis procedures will then be defined in such a way that enables stakeholders to use them for each major class of ESS. Within risk assessment and management, the goal is that the framework and methodologies for assessing and managing deployment risk for ESS are accepted and adopted by industrial and regulatory stakeholders. Towards this end, current frameworks will be catalogued, and a model risk framework will be identified for specific ESS technologies. The ultimate goal for first and second responders is the complete awareness of hazards and the ability to address them in the field. Finally, it is the goal that codes, standards and regulations enable the deployment of safe ESS. Gaps in CSR that require additional technical research, development, and demonstration will be identified and addressed.

1.0 Introduction and Motivation

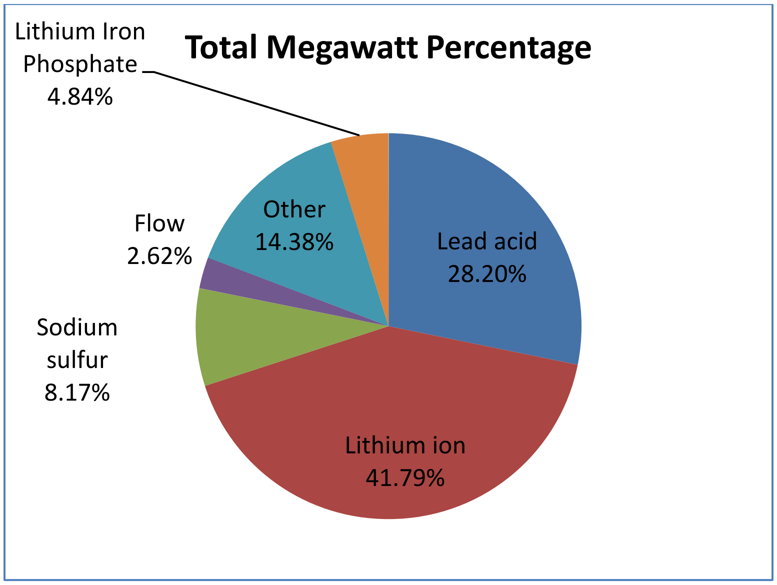
Grid energy storage systems are "enabling technologies"; they do not generate electricity, but they do enable critical advances to modernize the electric grid. For example, there have been numerous studies that have determined that the deployment of variable generation resources will impact the stability of grid unless storage is included.[5] Additionally, energy storage has been demonstrated to provide key grid support functions through frequency regulation.[6] The diversity in the performance needs and deployment environments drive the need of a wide array of storage technologies. Often, energy storage technologies are categorized as being high-power or high-energy. This division greatly benefits the end user of energy storage systems because it allows for the selection of a technology that fits an application's requirements, thus reducing cost and maximizing value. For example, frequency regulation requires very rapid response, i.e. high-power, but does not necessarily require high energy. By contrast, load-shifting requires very high-energy, but is more flexible in its power needs. Uninterruptible power and variable generation integration are applications where the needs for high-power versus high-energy fall

[5] Denholm, Paul; Ela, Erik; Kirby, Brendan; Milligan, Michael. "The Role of Energy Storage with Renewable Electricity Generation." National Renewable Energy Laboratory Technical Report: NREL/TP-6A2-47187. Jan 2010.

[6] Arseneaux, Jim. "20 MW Flywheel Frequency Regulation Plant (Hazle Spindle)." Beacon Power, LLC. EESAT Conference. Oct 2013.

somewhere in between the aforementioned extremes. Figure 1 shows the current energy storage techniques deployed onto the North American grid.[7] This variety in storage technologies increases the complexity in developing a single set of protocols for evaluating and improving the safety of grid storage technologies and drives the need for understanding across length scales, from fundamental materials processes through full scale system integration.

Figure 1. Percentage of Battery Energy Storage Systems Deployed[8]



The variety of deployment environments and application spaces compounds the complexity of the approaches needed to validate the safety of energy storage systems. The difference in deployment environment impacts the safety concerns, needs, risk, and challenges that affect stakeholders. For example, an energy storage system deployed in a remote location will have very different potential impacts on its environment and first responder needs than a system deployed in a room in an office suite, or on the top floor of a building in a city center. The closer the systems are to residences, schools, and hospitals, the higher the impact of any potential incident regardless of system size. Therefore, it is critical that the safety risk of each system be mitigated and the appropriate responder preparedness tailored to the specific risks, exposured

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[7] DOE Global Energy Storage Database. July 2014.

[8] "Total Megawatt Percentage" includes contracted batteries as well as batteries with verification in progress. "Other" includes ultrabatteries, nickel ion, nickel cadmium, lithium polymer, lithium nickel cobalt aluminum, sodium nickel chloride, lithium ferrous phosphate, lead carbon, hybrid, and aqueous hybrid ion.

population and infrastructure, which reduces the potential losses and is key in determining the overall cost of ownership.

The discussion within this document explores the current landscape of energy storage deployments and technologies and identifies specific areas in validation techniques, incident response and safety codes, standards and regulations (CSR) where the community should focus its efforts. Ultimately, it is the goal of this strategic plan to lay the groundwork necessary to ensure the safety of energy storage deployments and instill confidence in the community of stakeholders who depend on an efficient, reliable and resilient electric grid.

2.0 Current State of Energy Storage Technologies

Each storage technology has unique performance characteristics that make it optimally suitable for certain grid services; however, the technologies are each at different maturity levels and are each deployed in varying amounts. These differences must be taken into consideration when addressing safety because the level of risk increases as the level of maturity decreases or the level of deployment increases. The different levels of maturity and deployment also illustrate which systems must immediately be validated as safe. As per the DOE Grid Strategy, "the categorization of 'deployed,' 'demonstrated,' and 'early stage,' is often blurred, and changes over time. Figure 2 lists technologies based on their present degree of adoption."[9]

Pumped hydro is one of the oldest and most mature energy storage technologies and represents 95% of the installed storage capacity. Other storage technologies, such as batteries, flywheels and others, make up the remaining 5% of the installed storage base, are much earlier in their deployment cycle and have likely not reached the full extent of their deployed capacity. Among these deployed storage technologies, this DOE OE Strategic Plan for Energy Storage Safety will focus primarily on batteries, with some attention to flywheels due to the rapid growth seen in these two relatively new grid-scale technologies.

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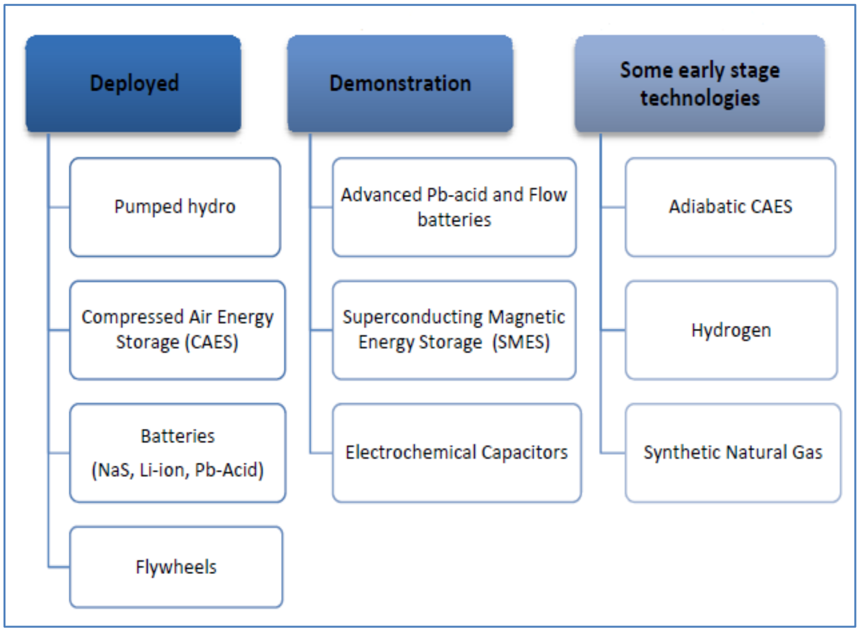
[9] Grid Energy Storage Strategy. U.S. Department of Energy, Dec. 2013, p. 16.

Figure 2. Maturity of Electricity Storage Technologies



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2.1 Pumped Hydro Storage

Pumped hydro is so established as a deployed storage technology that this is not a focus technology for addressing safety concerns. With over 100 GW of installed capacity in the world, and the first hydroelectric plants opening in the 1800s, the technology is well understood without large uncertainty remaining concerning its safety and reliability.

2.2 Compressed Air Energy Storage (CAES)

Although CAES is an earlier stage technology, the mechanics of conventional CAES have characteristics analogous to many commercial industrial processes, such as conventional piping and fittings. Established safety codes address the above-ground CAES pressure vessel concerns which are well mitigated with pressure relief valves implemented at pressures equal to 40% of the rupture pressure in steel vessels and 20% of the rupture pressure for fiber-wound vessels, as defined by code. Such established safety protocols in industry result in reduced concerns and uncertainly with respect to safety in CAES deployments.

2.3 Superconducting Magnetic Energy Storage (SMES)

SMES technology uses a superconducting coil to store DC current. As an early stage technology, it has not proven itself to be a viable piece of the bulk storage market for deployed technologies. As such, is not addressed in this strategy.

2.4 Flywheels

Though flywheels are relative newcomers to the grid energy storage arena, they have been used as energy storage devices for centuries with the earliest known flywheel being from 3100 BC Mesopotamia. Grid scale flywheels operate by spinning a rotor up to tens of thousands of RPM storing energy in a combination of rotational kinetic energy and elastic energy from deformation of the rotor. These systems typically have large rotational masses that in the case of a catastrophic radial failure need a robust enclosure to contain the debris. However, if the mass of the debris particles can be reduced through engineering design, the strength, size and cost of the containment system can be significantly reduced. For example, laminated flywheels where the bonding strength of the layers is lower that the tensile strength within a layer will "unwind" rather than throw off large arc sections of the rotor material. The engineering designs and safety factors in containing flywheels are not currently widely established by the CSRs and require further research. Current safety validation testing involves burst testing to probe containment integrity, loss-of-vacuum testing, overspeed testing of systems, as well as fatigue testing of sample materials. [10]

2.5 Capacitors

Electrochemical capacitors prompt similar concerns in terms of the safety of the stored energy within an electrochemical device and failures of devices. They are not therefore addressed independently here, but they do deserve attention in understanding and addressing safety for grid storage. Validation techniques can be considered in the context of approaches taken for battery safety.

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[10] Flynn, M. M., Zierer J. J., Thompson, R. C. "Performance Testing of a Vehicle Flywheel Energy System" SAE Technical Paper Series. 2005.
http://www.utexas.edu/research/cem/Energy_storage_photos/2005_Performance%20Testing%20of%20a%20Vehicular%20Flywheel%20Energy%20System%202005-01-0809.pdf

Electrostatic and electrolytic capacitors are used in board design and are a very common cause of faults that can lead to cascading failure resulting in voltage and or current surges and overcharge of storage devices or temperature rises that can lead to ignition of flammable materials either within the capacitor or adjacent components.

2.6 Batteries

As electrochemical technologies, battery systems used in grid storage can be further categorized as redox flow batteries, hybrid flow batteries, and secondary batteries without a flowing electrolyte. For the purposes of this document, vanadium redox flow batteries and zinc bromine flow batteries are considered for the first two categories, and lead-acid, lithium ion, sodium nickel chloride and sodium sulfur technologies in the latter category. As will be discussed in detail in this document, there are a number of safety concerns specific to batteries that should be addressed, e.g. release of the stored energy during an incident, cascading failure of battery cells, and fires.

3.0 State of Safety Validation in the U.S.

Several significant issues in the current state of safety validation that must be addressed, including: passive safety plans, reactionary safety approaches, and ineffective first response procedures. First, the typical safety plan is passive, i.e. addressing each deployed system on a case-by-case basis rather than having global standards and protocols for safety. Historically, technology has typically led regulations, i.e. each installation of megawatt-sized, battery-based energy storage systems since the 1980s has marked a technological milestone in the development and understanding of the operational characteristics of such large-scale battery systems. Because each installation was unique in size, functionality, and design, the unifying safety validation techniques and national CSR for the integrations and use of full systems was absent. While there are substantial CSR in existence for individual components within a storage system, current safety documents must now be updated to address the entire integrated system in order to fully validate its operational safety. Overall system safety is still determined on an installation-by-installation basis by the system vendor (either the system manufacturer or the system installer) who is charged with satisfying owner requests and meeting any applicable CSR on behalf of the owner. The CSR currently available and directives guide the approach to safety of systems on the grid side of the meter. However, fire marshals typically have little oversight of activities on the grid side of the meter, which is typically under the jurisdiction of the public utilities commission. On the customer side, a similar approach is found, but is based on enforcement of adopted CSR by state and local agencies. This individualized approach for evaluating safety is the current *modus operandi* and ultimately hinders the time and cost of deploying systems.

Second, safety approaches are reactionary instead of proactive and predictive, thus unnecessarily increasing costs with irrelevant and ineffective techniques. Energy storage systems manufacturers, owners, and installers will use validation techniques for new systems based on previous installation experience, disregarding differences in system type, battery chemistry, total capacity, or deployment environment. The result of this approach is that the validation techniques are not comprehensive, though substantial amounts of money and time are spent to initiate them. An example of ineffective safety validation can be found in method used by the Puerto Rico Electric Power Authority (PREPA) to install a 20 MW/17 MWh spinning reserve/frequency regulation battery system in 1994.[11] This installation was patterned after a similarly-sized, flooded-cell, lead-acid battery system installed at the West Berlin Electric Utility Company (BEWAG) in Berlin in 1986.[12] Even though the PREPA installation was fashioned after the BEWAG system, the local fire marshal in San Juan determined that the mandatory safety requirements at the PREPA installation were significantly different. Differences in the battery chemistry, the application space, and the deployment environment between the two systems were not accounted for before PREPA was installed. This initial oversight resulted in costly additional risk mitigation measures. PREPA was required to provide a structural design on the second floor, which housed the battery, as a virtual swimming pool to hold all the water required to extinguish a potential fire. In addition, PREPA was required to store on site a large quantity of water for firefighting, along with its necessary pumping infrastructure. The additional cost and space requirements, caused by the altered structural design of the building, dramatically increased the deployment cost.

System owners are often required to establish a safety margin based on their best engineering guess rather than on scientifically derived validation techniques developed from an

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[11] Farber-DeAnda, Mindi. Boyes, John D. Wenceslao, Torres. “Lessons Learned from the Puerto Rico Battery Energy Storage System.” Sandia National Laboratories, 1999.

[12] Wagner, Richard. “High-power lead-acid batteries for different applications.” Journal of Power Sources, Nov. 2004. p 496.

understanding of the active processes and limitations of the system, as was the case with the PREPA system. As safety validation techniques are developed, validated, and documented for each type of storage technology in every potential deployment environment, system owners will be able to accurately estimate the full cost of each deployed system, including the risks associated with insuring the installation. Significant decreases in uncertainty and gains in process efficiencies will be the results of the development and documentation of these validation techniques. Additionally, standard validation and deployment techniques can be used to improve the safety and knowledge base of the first responders.

The third issue is that the historic and current first response procedures have also suffered as a result of reactive, ineffective safety validation techniques and lack of standardized documentation. Often, due to a lack of local experience in such events, response practices are based on events that occurred in different technologies, but were reported nationally. In the late 1980s, the question of fire safety arose concerning the lead-acid inside the containerized battery system PM250. The enclosed container design had to allow for the safe and fail-safe venting of hydrogen emitted during charging. Consideration was also given to how a first responder could look inside the container to observe the interior condition without opening the container's large doors.[13] However, neither design decision was addressed by the governing safety code, which lacked specifications about the design of hydrogen venting or the size and location of the glass portholes.

A reactive approach to energy storage safety is no longer viable. The number and types of energy storage deployments have reached a tipping point with dramatic growth anticipated in the next few years fueled in large part by major, new, policy-related storage initiatives in California[14], Hawaii[15], and New York.[16] The new storage technologies likely to be deployed in

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[13] Corey, Garth; Nerburn, William; Porter, David. "Final Report on the Development of a 250-kW Modular, Factory-Assembled Battery Energy Storage System." Sandia National Laboratories, 1998.

[14] Program Opportunity Notice: "Developing Advanced Energy Storage Technology Solutions to Lower Costs and Achieve Policy Goals," PON-13-302. http://www.energy.ca.gov/contracts/PON-13-302/00_PON-13-302_Energy_Storage_2014-07-31.pdf

[15] Hawaiian Electric. O'ahu Energy Storage System, Request for Proposals No. 072114-01. http://www.hawaiianelectric.com/vcmcontent/StaticFiles/pdf/ESS_RFP_No_072114-01.pdf

[16] Reforming the Energy Vision: NYS Department of Public Service Staff Report and Proposal. Case 14-M-0101. 2014. http://www3.dps.ny.gov/W/PSCWeb.nsf/96f0fec0b45a3c6485257688006a701a/26be8a93967e604785257cc40066b91a/$FILE/ATTK0J3L.pdf/Reforming%20The%20Energy%20Vision%20%28REV%29%20REPORT%204.25.%2014.pdf

response to these and other initiatives are maturing too rapidly to justify moving ahead without a unified scientifically based set of safety validation techniques and protocols. A compounding challenge is that startup companies with limited resources and experience in deployment are developing many of these new storage technologies. Standardization of the safety processes will greatly enhance the cost and viability of new technologies, and of the startup companies themselves. The modular nature of ESS is such that there is just no single entity clearly responsible for ESS safety; instead, the each participant in the energy storage community has a role and a responsibility. The following sections outline the gaps in addressing the need for validated grid energy storage system safety.

4.0 Key Aspects for Addressing Energy Storage Safety

Safety of any new technology can be broadly viewed as having three intimately linked aspects, as follows: 1) the system must be engineered and validated to the highest level of safety; 2) techniques and processes must be developed to respond to incidents when they occur; and 3) best practices and system requirements must then be reflected in CSR so that there is uniform, consistent, understandable and enforceable criteria that must be satisfied when designing, building, testing, and deploying the system. It is clear within the grid energy storage community that specific efforts must be started or expanded to address each of these three areas.[17] Specifically, as the materials, technologies, and deployment applications for storing energy are created, new techniques and protocols must be developed to validate their safety and ensure the risk of failure and loss is minimized. These new techniques and protocols will allow manufacturers to design the systems to be as safe as possible, especially for the first and second responders. These techniques will additionally be used to educate first responders on the associated risk of responding to an incident involving the new technologies. Finally, codes, standards, and regulations will be developed to efficiently memorialize these design rules, response procedures and safety performance metrics to all stakeholders.

[17] DOE OE Energy Storage Safety Workshop, Albuquerque, NM. 2014.

5.0 Validation Techniques

To date, the most extensive energy storage safety and abuse R&D efforts have been done for Electric Vehicle (EV) battery technologies. These efforts have been limited to lithium ion, lead-acid and nickel metal hydride chemistries and, with the exception of grid-scale lead-acid systems, are restricted to smaller size battery packs applicable to vehicles.[18] Lessons learned from EV safety R&D can be useful in developing the grid storage energy storage safety area, and in fact, the use of EV batteries that are beyond their automotive service life in grid storage is emerging as a viable second life. However, the increased scale, complexity, and diversity in technologies being proposed for grid- scale storage necessitates a comprehensive strategy for adequately addressing safety in grid storage systems. The technologies deployed onto the grid fall into the categories of electro-chemical, electromechanical, and thermal, and are themselves within different categories of systems, including CAES, flywheels, pumped hydro and SMES. This presents a significant area of effort to be coordinated and tackled in the coming years, as a number of gap areas currently exist in codes and standards around safety in the field. R&D efforts must be coordinated to begin to address the challenges.

5.1 Current Validation Techniques

An energy storage system can be categorized primarily by its power, energy and technology platform. For grid-scale systems, the power/energy spectrum spans from smaller kW/kWh to large MW/MWh systems. Smaller kW/kWh systems can be deployed for residential and community storage applications, while larger MW/MWh systems are envisioned for electric utility transmission and distribution networks to provide grid level services. This is in contrast to electric vehicles, for which the U.S. Advanced Battery Consortium (USABC) goals are both clearly defined and narrow in scope with an energy goal of 40 kWh. While in practice some EV packs are as large as 90 kWh, the range of energy is still small compared with the grid storage applications. This research is critical to the ability of first responders to understand the risks posed by ESS technologies and allow for the development of safe stratagies to minimize risk and mitigate the event.

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[18] Doughty, Daniel H.; Pesaran, Ahmad A. "Vehicle Battery Safety Roadmap Guidance." National Renewable Energy Laboratory. Oct. 2012. http://www.nrel.gov/docs/fy13osti/54404.pdf

Table 1. Range of Storage Technology and Size

Storage space	Technologies	Application	Storage Size (energy)	Storage Size (power)
Electric Vehicle Technology	Batteries (Li-ion, NiMH, Pb-acid)	City and highway driving	40 – 90 kWh	80 kW[19]
Stationary Storage	Batteries, CAES, flywheels, pumped hydro and SMES	Over 17 use cases identified[20]	5 kWh – 1 GWh[21]	10 kW – 1 GW

Furthermore, the diversity of battery technologies and stationary storage systems is not generally present in the EV community. Therefore, the testing protocols and procedures used historically and currently for storage systems for transportation are insufficient to adequately address this wide range of storage systems technologies for stationary applications. Table 1 summarizes the high level contrast between this range of technologies and sizes of storage in the more established area of EV. The magnitude of effort that must be taken on to encompass the needs of safety in stationary storage is considerable because most research and development to improve safety and efforts to develop safety validation techniques are in the EV space.

Notably, the size of EV batteries ranges by a factor of two; by contrast, stationary storage scales across many orders of magnitude. Likewise, the range of technologies and uses in stationary storage are much more varied than in EV. Therefore, while the EV safety efforts pave the way in developing R&D programs around safety and developing codes and standards, they are highly insufficient to address many of the significant challenges in approaching safe development, installation, commissioning, use and maintenance of stationary storage systems.

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[19] Mackenzie, Angus. "2013 Motor Trend Car of the Year: Tesla Model S. Motor Trend. 2013.

[20] Akhil, Abbas; et al. "DOE/EPRI 2013 Electricity Storage Handbook in Collaboration with NRECA." Sandia National Laboratories. July 2013.

[21] The Tesla Motors Team. "A Supercharging Milestone." Tesla Motors. July 2014.

An additional complexity of grid storage systems is that the storage system can either be built on-site or pre-assembled, typically in shipping containers. These pre-assembled systems allow for factory testing of the fully integrated system, but are exposed to potential damage during shipping. For the systems built on site, the assembly is done in the field; much of the safety testing and qualification could potentially be done by local inspectors, who may or may not be as aware of the specifics of the storage system. Therefore, the safety validation of each type of system must be approached differently and each specific challenge must be addressed.

5.2 Areas of Interest in Safety Validation

Given the maturity and documented use of pumped hydro and CAES, batteries and flywheels are currently the primary focus for enhanced grid-scale safety.   For these systems, the associated failure modes at grid-scale power and energy requirements have not been well characterized and there is much larger uncertainty around the risks and consequences of failures. This uncertainty around system safety can lead to barriers to adoption and market success, such as difficulty with assessing value and risk to these assets, and determining the possible consequences to health and the environment. To address these barriers, concerted efforts are needed in the following areas:

- Materials Science R&D – Research into all device components
- Engineering controls and system design
- Modeling
- System testing and analysis
- Commissioning and field system safety research

It is a notable challenge within the areas outlined above to develop understanding and confidence in relating results at one scale to expected outcomes at another scale, or predicting the interplay between components, as well as protecting against unexpected outcomes when one or more failure mode is present at the same time in a system. Extensive research, modeling and validation are required to address these challenges. Furthermore, it is necessary to pool the analysis approaches of failure mode and effects analysis (FMEA) and to use a safety basis in both research and commissioning to build a robust safety program. Furthermore, identifying, responding and mitigating to any observed safety events are critical in validating the safety of storage.

A holistic view with regard to setting standards to ensure thorough safety validation techniques is the desired end goal; the first step is to study on the R&D level failure from the cell to system level, and from the electrochemistry and kinetics of the materials to module scale behavior. Detailed hazards analysis must be conducted for entire systems in order to identify failure points caused by abuse conditions and the potential for cascading events, which may result in large scale damage and/or fire. While treating the storage system as a “black box” is helpful in setting practical standards for installation, understanding the system at the basic materials and chemistry levels and how issues can initiate failure at the cell and system level is critical to ensure overall system safety.

In batteries, understanding the fundamental electrochemistry and materials changes under selected operating conditions helps guide the cell level safety. Knowledge of cell-level failure modes and how they propagate to battery packs guides the cell chemistry, cell design and integration. Each system has different levels of risk associated with basic electrochemistry that must be understood; the tradeoff between electrochemical performance and safety must be managed. There are some commonalities of safety issues between storage technologies. For example, breeching of a Na/S (NAS) or $Na/NiCl_2$ (Zebra) battery could result in exposure of molten material and heat transfer to adjacent cells.[22,23,24] Evolution of H_2 from lead-acid cells or H_2 and solvent vapor from lithium-ion batteries during overcharge abuse could results in a flammable/combustible gas mixture.[25,26,27,28] Thermal runaway in lithium-ion (Li-ion) cells could transfer heat to adjacent cells and propagate the failure through a battery.[29] Moreover,

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[22] “Cause of NAS Battery Fire Incident” NGK Insulators, LTD. June, 2012.

[23] A. V. Van Zyl; C.-H Dustmann (Nov. 1995). “Safety Aspects of Zebra High Energy Batteries,” in Conference Proceedings, WEVA Conference for Electric Vehicle Research, Development and Operation, November 13, 14, 15, 1995; Paris. Bruxelles, Belgium. pp. 57–63.

[24] Current Status of Health and Safety Issues of Sodium/Metal Chloride (Zebra) Batteries” NREL/TP-460-25553. November, 1998.

[25] A. J. Salkind, A. G. Cannone, F. A. Trumbure in “The Handbook of Batteries” D. Linden and T. B. Reddy, 3rd Edition, 2002, pp. 23.77-23.78.

[26] A. W. Metwally “Generic environmental and safety assessment of five battery energy storage systems”, Electr. Power Res. Inst. 1982

[27] D. P. Abraham, E. P. Roth, R. Kostecki, K. McCarthy, S. MacLaren, D. H. Doughty, “Diagnostic examination of thermally abused high-power lithium-ion cells” J. Power Sources, 161. 2006, pp. 648-657

[28] G. Nagasubramanian and C. J. Orendorff, “Hydrofluoroether electrotes for lithium-ion batteries: Reduces gas decomposition and nonflammable” J. Power Sources, 196. 2011, pp. 8604-8609.

[29] Mikolajczak, Celina; Kahn, Michael; White, Kevin; Long, Richard Thomas. “Lithium-Ion Batteries Hazard and Use Assessment.” Exponent Failure Analysis Associates, Inc. July 2011.

while physical hazards are often considered, health and environmental safety issues also need to be evaluated to have a complete understanding of the potential hazards associated with a battery failure. These may include the toxicity of gas species evolved from a cell during abuse or when exposed to abnormal environments, [30,31] toxicity of electrolyte during a cell breech or spill in a Vanadium redox flow battery (VRB),[32] environmental impact of water runoff used to extinguish a battery fire containing heavy metals.[33] Flywheels provide an entirely different set of considerations, including mechanical containment testing and modeling, vacuum loss testing, and material fatigue testing under stress. A holistic approach needs to be taken to address all of the cell or component level through system-level safety issues with adequate mitigations, diagnostics, monitoring, and engineered controls.

Failure mode and effects analysis (FMEA) is conducted in installations. Research must consider current FMEA tactics specific to stationary storage, identify weaknesses in their execution with special attention to systems that have encountered field failure caused by abuse, and failures that were not well controlled, leading to cascading events resulting in large scale damage and/or fire. A comprehensive look at system level concerns with regard to failures and safety can be approached when R&D is incorporated into the standard basis for safety.

5.3 Materials Science R&D

The topic of Li-ion battery safety is rapidly gaining attention as the number of battery incidents increases. Recent incidents, such as a cell phone runaway during a regional flight in Australia and a United Parcel Service plane crash near Dubai, reinforce the potential consequence of Li-ion battery runaway events. The sheer size of grid storage needs and the operational demands make it increasingly difficult to find materials with the necessary properties, especially the required thermal behavior to ensure fail-proof operation. The main failure modes for these battery systems are either latent (manufacturing defects, operational heating, etc.) or abusive (mechanical, electrical, or thermal).

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[30] A. J. Salkind, A. G. Cannone, F. A. Trumbure in "The Handbook of Batteries" D. Linden and T. B. Reddy, 3rd Edition, 2002, pp. 23.77-23.78.

[31] D. P. Abraham, E. P. Roth, R. Kostecki, K. McCarthy, S. MacLaren, D. H. Doughty, "Diagnostic examination of thermally abused high-power lithium-ion cells" J. Power Sources, 161. 2006, pp. 648-657.

[32] "Toxicology Profile for Vanadium" U.S. Department of Health and Human Services, Public Health Service, Agency for Toxic Substances and Disease Registry. September 2012.

[33] Wesoff, Eric. "Battery Room Fire at Kahuku Wind-Energy Storage Farm." Green Tech Grid. August 2012.

Any of these failures can increase the internal temperature of the cell, leading to electrolyte decomposition, venting, and possible ignition. While significant strides are being made, major challenges remain in combating solvent flammability still remain, which is the most significant area that needs improvement to address safety of Li-ion cells, and is therefore discussed here in greater detail. To mitigate thermal instability of the electrolyte, a number of different approaches have been developed with varied outcomes and moderate success. Conventional electrolytes typically vent flammable gas when overheated due to overcharging, internal shorting, manufacturing defects, physical damage, or other failure mechanisms. The prospects of employing Li-ion cells in applications depend on substantially reducing the flammability, which requires materials developments (including new lithium salts) to improve the thermal properties. One approach is to use fire retardants (FR) in the electrolyte as an additive to improve thermal stability. Most of these additives have a history of use as FR in the plastics industry. Broadly, these additives can be grouped into two categories—those containing phosphorous and that containing fluorine. A concerted effort to provide a hazard assessment and classification of the event and mitigation when an ESS fails, either through internal or external mechanical, thermal, or electrical stimulus is needed by the community.

Significant efforts have been made to develop tests to determine the safety margin in Li-ion batteries in both mobile devices and vehicles. For example, significant efforts have been made in the qualification of the response to battery cell thermal runaway, [34,35,36,37] safety response in packs to mechanically induced failure,[38] and model thermal abuse of cells.[39] A comprehensive report prepared by Exponent Failure Analysis Associate, Inc. for the Fire Protection Research Foundation provides a detailed review of validation techniques as part of the Lithium-Ion Batteries Hazard and Use Assessment.[40] This review and its references describe the state of

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[34] J.R. Dahn, E.W. Fuller, M. Obrovac, U. Vonsacken. “Solid State Ionics.” 69. 1994, 265.
[35] D. Belov, M.H. Yang, “Solid State Ionics.” 179. 2008, 1816.
[36] D. Belov, M.H. Yang, J. “Solid State Electr.” 12, 2008, 885.
[37] S.J. Harris, A. Timmons, W.J. Pitz. “J Power Sources.” 193, 2009, 855.
[38] R.M. Spotnitz, J. Weaver, G. Yeduvaka, D.H. Doughty, E.P. Roth. “J Power Sources.” 163, 2007, 1080.
[39] G.H. Kim, A. Pesaran, R. Spotnitz. “J Power Sources” 170, 2007, 476.

understanding around battery failures and research into improved safety at that time, but are limited in the material systems and the size of the systems reviewed.

5.4 Electrolyte Safety R&D

The combustion process is a complex chemical reaction by which fuel and an oxidizer in the presence of heat react and burn. Convergence of heat (an oxidizer) and fuel (the substance that burns) must happen to have combustion. The oxidizer is the substance that produces the oxygen so that the fuel can be burned, and heat is the energy that drives the combustion process. In the combustion process a sequence of chemical reactions occur leading to fire.[41] In this situation a variety of oxidizing, hydrogen and fuel radicals are produced that keep the fire going until at least one of the three constituents is exhausted.

5.4.1 Electrolytes

Despite several studies on the issue of flammability, complete elimination of fire in Li-ion cells has yet to be achieved. One possible reason for the failure could be linked to lower flash point (F_P) (<38.7 °C) of the solvents.[42] Published data shows that polyphosphazene polymers and ionic liquids used as electrolytes are nonflammable.[43] However, the high F_P of these chemicals is generally accompanied by increased viscosity, thus limiting low temperature operation and degrading cell performance at sub-ambient temperatures. These materials may also have other problems such as poor wetting of the electrodes and separator materials, excluding them from use in cells despite being nonflammable.

Ideally, solvents would be used that have no F_P while simultaneously exhibiting ideal electrolyte behavior (see below for a number of critical properties that the electrolytes need to meet) and would remain liquid at low temperatures down to -50 ºC or below for use in Li-ion cells. A number of critical electrochemical and thermal properties are given below that FR have to meet simultaneously. The tradeoffs between properties are possible but when it comes to safety there cannot be tradeoffs.

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[40] Mikolajczak, Celina; Kahn, Michael; White, Kevin; Long, Richard Thomas. "Lithium-Ion Batteries Hazard and Use Assessment." Exponent Failure Analysis Associates, Inc. July 2011.
[41] S.M. Sarathy, C.K. Westbrook, M. Mehl, W.J. Pitz, C. Togbe, P. Dagaut, H. Wang, M.A. Oehlschlaeger, U. Niemann, K. Seshadri, P.S. Veloo, C. Ji, F.N. Egolfopoulos, T. Lu. "Combust Flame" 158, 2011, 2338.
[42] "CRC Handbook of Chemistry and Physics", 79th ed., edited by D. R. Lide. CRC, Boca Raton. 1998–1999.
[43] S. Werner, M. Haumann, P. Wasserscheid, Annu Rev. "Chem Biomol Eng." 1, 2010, 203

- High voltage stability
- Comparable conductivity to traditional electrolytes
- Lower flame propagation rate or no fire at all
- Lower self-heating rate
- Stable against both the electrodes
- Able to wet the electrodes and separator materials
- Higher onset temperature for exothermic peaks with reduced overall heat production
- No miscibility problems with co-solvents

Electrolyte non-flammability is essential for cell safety. Enhanced safety of electrolytes containing FR additives is mostly accompanied by performance degradation including low capacity utilization, high rate of capacity fade, or poor low temperature performance. Additionally, some are electrochemically unstable and are consumed during cycling, becoming unavailable for cell protection with time. Furthermore, limited information is available in the open literature on the performance of additives in large capacity cells under actual use conditions and subsequent abuse conditions. The higher energy density of Li-ion cells can only result in a more volatile device, and while significant efforts have been put forth to address safety, significant research is still needed. To improve safety of Li-ion batteries, the electrolyte flammability needs significant advances or further mitigation is needed in areas that will contain the effects of failures to provide graceful failures with safer outcomes in operation.

5.4.2 Additives

The most commonly accepted mechanism for fire propagation relies on a radical generation mechanism. Ground state oxygen absorbs heat and produces energetic and extremely reactive singlet oxygen. The identified mechanism clearly indicates that hydrogen radical and singlet oxygen play a key role in sustaining the flame.[44] This is the target for many of the materials proposed as FR additives. If a FR material is able to sufficiently bind to the free radicals during the reaction cascade, then propagation of the flame will be suppressed.

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[44] J.L. Jurs. "Development and Testing of Flame Retardant Additives and Polymers." Rice University. 2007, 303.

Researchers have predominantly performed Differential Scanning Calorimetry (DSC) measurements on electrolytes to determine thermal stability with and without the FR. The ideal outcome is that the electrolyte with FR show very little peak in the DSC traces and even then only at higher temperatures compared to the electrolyte without the FR.[45] This observation seems to suggest that the FR additive improves the thermal stability of the electrolyte. Others have chosen to employ standard test procedures from the American Society for Testing and Materials (ASTM), Underwriters Laboratories (UL), and International Electrotechnical Commission (IEC) such as ASTM D-5306, ASTM D2863, UL-94VO, and IEC 62133 to compute both the self-extinguishing time (SET) and the limited oxygen index (LOI) to evaluate the flammability of the electrolytes. The shorter the SET and higher the LOI (this is the % of oxygen needed in the O_2/N_2 mixture to keep the electrolyte burning for at least 60s), the less flammable the electrolyte. In general, the electrolyte with the additives shows shorter SET and higher LOI than the electrolyte without FR. Descriptions of the thrust of the different ASTM and UL tests were discussed in depth by M. Otsuki, *et al.* [46] See Appendix A for a table of the variety of new and novel FR materials that have been synthesized and studied as well as low flash point electrolytes that have been developed to fight flame ignition.

In the vapor phase, the traditionally accepted mechanism is that FR decomposes, producing phosphorous or halogen radicals that act as scavengers and react with hydrogen radicals, thereby terminating the free radical reaction. Despite wide availability for FR materials, two primary classes of materials have been investigated extensively for use in Li-ion batteries, which are phosphorus-containing materials and fluorine containing materials. The phosphorous-containing materials primarily rely on the free radical scavenging mechanism, but on rare occasion inhibit reaction through char formation on the reactive surface. Alternately replacing hydrogen with fluorine, the compound should be more thermally stable due to the decrease in the available hydrogen for radical production. By eliminating the generation of hydrogen radicals, flammability could potentially be minimized or eliminated; however, advances to date are at the R&D scale.

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[45] E-G Shim, T-H Nam, J-G Kim, H-S Kim, S-I Moon. "Electrochimica Acta." 53, 2007, 650.

[46] "Lithium-Ion Batteries: Science and Technology." Edited by M. Yoshio, R.J. Brodd, A. Kozawa. Springer-Verlag New York, LLC, 278, 2009.

5.4.3 Electrodes, separators, current collectors, casings, cell format headers and vent ports

While electrolytes are by far the most critical component in Li-ion battery safety, research has been pursued into safety considerations around the other components of the cell. These factors can become more critical as research continues in wider ranges of chemistries for stationary storage. Again, research to date has focused on Li-ion devices; however, insights in these components may be leveraged in designing safer technologies across electrochemical solutions. Within materials R&D, the exponent review describes efforts into improving safety in battery components including safer cathodes and separators in addition to electrolytes. It also details the state of other cell components in the context of hazards and safety; including anodes, charge collectors, casing, and safety devices including charge interrupt devices and positive temperature coefficient switches.[47]

5.4.4 Capacitors

Electrostatic capacitors are a major failure mechanism in power electronics. These predominately fail because of the strong focus on low cost devices, and low control over manufacturing. In response, they are used at a highly de-rated level, and often with redundant design. When they fail they often show slow degradation with decreasing resistivity leading eventually to shorting. Cascading failures can lead to higher consequence failures elsewhere in a system. Arcs or cascading failures can occur. The added complexity of redundant design is a safety risk. While there is a niche market for high reliability capacitors, they are not economically viable for most applications, including grid storage. These devices are made of precious metals and higher quality ceramic processing that leads to fewer oxygen vacancies in the device.

Polymer capacitors can have a safety advantage as they can be self-healing, and therefore graceful failure; however these are poor performers at elevated temperatures and are flammable. Testing of capacitors currently involves putting a DC bias or increasing the temperature to observe accelerated breakdown.

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[47] Mikolajczak, Celina; Kahn, Michael; White, Kevin; Long, Richard Thomas. "Lithium-Ion Batteries Hazard and Use Assessment." Exponent Failure Analysis Associates, Inc. July 2011.

Currently, the low cost and low reliability of capacitors make them a very common component that fails in devices, affecting the power electronics and providing a possible trigger for a cascading failure. While improved reliability has been achieved in capacitors such devices are cost prohibitive due to their manufacturing and testing. Development of improved capacitors at reasonable cost, or design to prevent cascading failures in the event of capacitor failure should be addressed.

5.4.5 Pumps tubing and tanks

Components specific to flow battery, and hybrid flow battery technologies have not been researched in the context of safety for battery technology. These include components such as pumps, tubing and storage tanks. Research from other areas that use similar components can be a starting point, but these demonstrate how the range of components is much broader than current R&D in battery safety.

5.4.6 Mechanical design and vacuum system

Similarly, components specific to flywheels have their own design considerations with respect to safety. The engineering design, and safety factors in containing flywheels is not currently widely established by CSR, and requires further research to be flushed out. Current safety validation testing involves burst testing to probe containment integrity, vacuum loss testing, overspeed testing of systems, as well as fatigue testing of sample materials.[48]

5.4.7 Manufacturing defects

The design of components and testing depends on understanding the range of purity in materials, and conformity in engineering. Defects are a large contributor to shorts in batteries for example. Understanding the reproducibility among parts, and the influence of defects on failure is critical to understanding and designing for safer storage systems.

[48] Sonnichsen, Eric. "Ensuring Spin Test Safety." Test Devices Inc. December 1993.

5.5 Engineering controls and system design

5.5.1 Circuit design and safety mechanisms

Current safety mechanisms for Li-ion batteries are typically two-fold; cell based devices designed to prevent thermal runaway of single cells and devices integrated into the battery system intended to preserve the overall stability of the battery pack. The most well-recognized single cell protective systems are the Positive Temperature Coefficient (PTC) and Current Interrupt Devices (CID). [49,50] PTCs are typically used as protection against external short circuits. In case of elevated current, the PTC self-heats and become more resistive, blocking additional current flow and preventing a runaway condition. CID protection affixes a current break point to the safety vent, blocking current flow if internal pressure builds up. These prevent current flow during any condition that can cause gas generation, such as overcharge and voltage reversal. Other cell based safety devices include shutdown separators, electrolyte additives (such as redox shuttles for overcharge protection and flame retardant additives), electroactive separators and less energetic active materials (see Appendix A). One component to keep in mind when considering shutdown separators is that disconnecting the string or module may or may not arrest the exothermic processes already be underway.

Large Li-ion battery packs typically include safety features integrated into their circuit design as well. Commonly, each series string will be outfitted with a blocking diode which prevents parallel strings from discharging through a battery with an unforeseen short circuit.[51] Researchers such as Kim *et al.*[52] have also proposed more robust circuits capable of mitigating the electrical impacts of a single cell failure. Manufacturers of large battery systems typically integrate proprietary control system as well, to control issues such as cell balance, cell temperature and estimation of battery life.

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[49] Balakrishnan, P.G., R. Ramesh, and T.P. Kumar. "Safety mechanisms in lithium-ion batteries." Journal of Power Sources, 2006. 155(2): p. 401-414.

[50] Friel, D.D. "*Battery Design*, in *Linden's Handbook of Batteries*." T.B. Reddy, Editor. 2011, McGraw Hill: New York. p. 5.1-5.23.

[51] Balakrishnan, P.G., R. Ramesh, and T.P. Kumar. "Safety mechanisms in lithium-ion batteries." Journal of Power Sources, 2006. **155**(2): p. 401-414.

[52] Kim, G.-H., et al. "Fail-safe design for large capacity lithium-ion battery systems." Journal of Power Sources. 2012, **210**(0): p. 243-253.

5.5.2 Fault detection

The science of fault detection within large battery systems is still within its infancy; most analysis and monitoring of large battery systems is focused on monitoring issues such as state of health and state of charge monitoring, however limited work has been performed. Offer *et al.*[53] first saw signs of a battery failure by monitoring the voltage of a battery system, then proceeded to diagnose the fault first using electrochemical impedance spectroscopy and a battery model constructed in Simulink. They found the fault related to faulty module construction rather than issues with the cell. Zheng *et al.*[54] proposed a fault detection method using Shannon entropy measurement to detect changes in internal or contact resistance within a battery. However, these works to not address detection of field failures (internal short circuits) or unstable batteries that may lead to a propagating failure. There are numerous sensors, including temperature, voltage, and off-gassing which have the potential to diagnose excursion. Additionally, software analytics can be critical tools in fault detection.

5.5.3 Software Analytics

In this day and age of information technology, any comprehensive research, development, and deployment strategy for energy storage should be rounded out with an appropriate complement of software analytics. Software is on a par with hardware in importance, not only for engineering controls, but for performance monitoring; anomaly detection, diagnosis, and tracking; degradation and failure prediction; maintenance; health management; and operations optimization. Ultimately, it will become an important factor in improving overall system and system-of-systems safety.

As with any new, potentially high consequence technology, improving safety will be an ongoing process. By analogy with airline safety, energy storage projects which use cutting-edge technologies would benefit from “black boxes” to record precursors to catastrophic failures. The black boxes would be located off-site and store minutes to months of data depending on the time scale of the phenomena being sensed. They would be required for large-scale installations,

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[53] Offer, G.J., et al. “Module design and fault diagnosis in electric vehicle batteries.” Journal of Power Sources. 2012. **206**(0): p. 383-392.

[54] Zheng, Y., et al. “Lithium ion battery pack power fade fault identification based on Shannon entropy in electric vehicles.” Journal of Power Sources, 2013. **223**(0): p. 136-146.

recommended for medium-scale installations, and optional for small installations. Evolving standards for what and how much should be recorded will be based on the results from research as well as experience.

Since some energy storage technologies are still early in their development and deployment, there should be an emphasis on developing safety cases. Safety cases should cover the full range of safety events that could reasonably be anticipated, and would therefore highlight the areas in which software analytics are required to ensure the safety of each system. Each case would tell a story of an initiating event, an assessment of its probability over time, the likely subsequent events, and the likely final outcome or outcomes. The development of safety cases need not be onerous, but they should demonstrate to everyone involved that serious thought has been given to safety. Standard or example cases could be developed for each technology to facilitate the creation of site-specific documentation.

5.6 Testing and Analysis

Validation techniques are guided primarily by CSR. Standard validation techniques are most evolved in the areas of lead-acid and Lithium-ion battery technologies due to their use in vehicle technologies. The most common experimental tests to assess specific risk from electrical, mechanical and environmental conditions are identified in Table 2. Tests that have not been standardized, and are under current R&D efforts are listed in the final row of this table. To date this work has been confined to the vehicle battery space, and not evaluated for their applicability to grid storage areas.

Table 2. Common Tests to Assess Risk from Electrical, Mechanical, and Environmental Conditions[55]

Condition	Tests
Electrical	Test of current flow Abnormal charging test, overcharging and charging time Forced discharge test
Mechanical	Crush test Impact test Shock test Vibration test
Environmental	Heating test Temperature cycling test Low pressure altitude test
Tests under development	Failure propagation Internal short circuit (non-impact test) Ignition/flammability IR absorption diagnostics Separator testing

The established tests for electrical, mechanical and environmental conditions are therefore tailored to identifying and quantifying the consequence and likelihood of failure in lead-acid and lithium ion technologies with typical analyses that include burning characteristics, off-gassing, smoke particulates, and environmental run off from fire suppression efforts. Even for the most studied abuse case of lithium ion technologies, some tests have been identified as very crude or ineffective with limited technical merit. For example, the puncture test, used to replicate failure under an internal short, is widely believed to lack the ability to accurately to mimic this particular failure mode. These tests are less likely to reproduce potential field failures when

[55] Florence, Laurie B. "Safety Issues for Lithium-Ion Batteries." UL. 2014. http://newscience.ul.com/wp-content/uploads/sites/30/2014/04/Safety_Issues_for_Lithium_Ion_Batteries.pdf

applied to technologies for which they were not originally designed. The above testing relates exclusively to cell/pack/module level and does not take into consideration the balance of the storage system. Other tests on Li-ion system are targeted at invoking and quantifying specific events; for example, impact testing and overcharging tests probe the potential for thermal runaway which occurs during anode and cathode decomposition reactions. Other failure modes addressed by current validation techniques include electrolyte flammability, thermal stability of materials including the separators, electrolyte components and active materials, and cell-to-cell failure.[56]

5.7 Modeling

Current efforts in modeling failure in batteries are again confined to those of interest in EV technologies. These efforts have focused on lithium ion battery technologies. Thermal impacts on lithium ion batteries in terms of performance, life and safety have been carried out using multi-physics battery modeling with respect to temperature dependent concerns.[57]

5.7.1 Gap areas and opportunities

An energy storage system deployed on the grid, whether at the residential (<10kW) or bulk generation scale on the order of MW, is susceptible to similar failures as described above for Li-ion. However, given the multiple chemistries and application space, there is a significant gap in our ability to understand and quantify potential failures under real-world conditions; in order to ensure safety as grid storage systems are deployed, it is critical to understand their potential failure modes within each deployment environment. Furthermore, it must be considered that grid-scale systems include at the very least: power electronics, transformers, switchgear, heating and cooling systems and housing structures or enclosures. The size and the variety of technologies necessitate a rethinking of safety work as it is adopted from current validation techniques in the electrified vehicle space.

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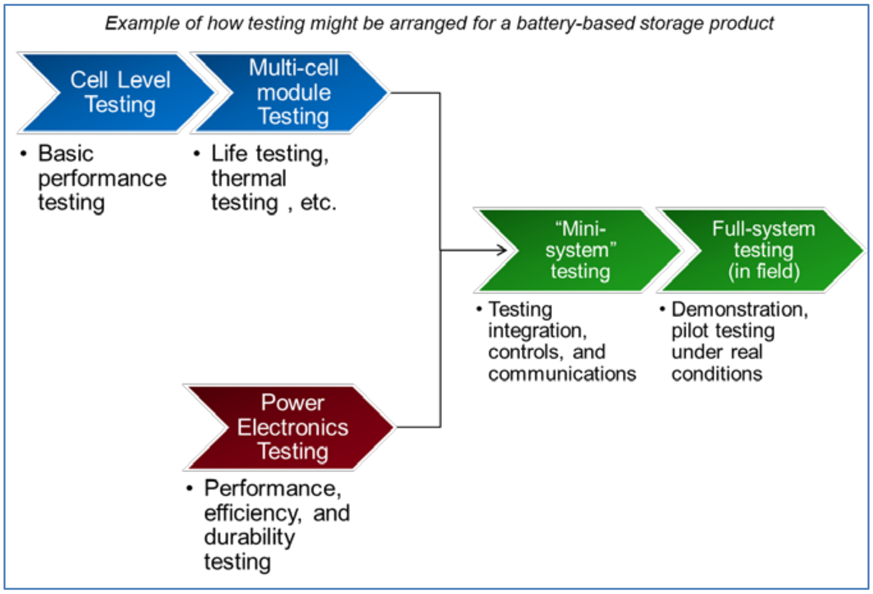
[56] Kim, Gi-Heon; Pesaran, Ahmad; Smith, Kandler. "Thermal Abuse Modeling of Li-Ion Cells and Propagation in Modules." 4th International Symposium on Large Lithium-Ion Battery Technology and Application. National Renewable Energy Laboratory. 2008. http://www.nrel.gov/vehiclesandfuels/energystorage/pdfs/43186.pdf

[57] Lin, Shaohua. "Multi-physics Modeling of Key Components in High Efficiency Vehicle Drive." University of Central Florida. Pg. iii. 2013. http://etd.fcla.edu/CF/CFE0005024/Shaohua_Lin_PHD_Dissertation_final.pdf

Safety work must encompass materials research and development, abuse testing to mimic potential threats within specific deployment environments, as well as simulations and modeling. This work cannot be limited solely to cell and module testing in order to achieve a holistic safety validation.

Figure 3. Example of Possible Testing Arrangement for a Battery-Based Storage Product



To address the component and system level safety concerns for all the technologies being developed for stationary energy storage, further efforts will be required to: understand these systems at the fundamental materials science, develop appropriate engineering controls, fire protection and suppression methods, system design, complete validation testing and analysis, and establish real world based models for operating. System level safety must also address several additional factors including the relevant codes, standards and regulations, the needs of first responders, and anticipate risks and consequences not covered by current CSR.

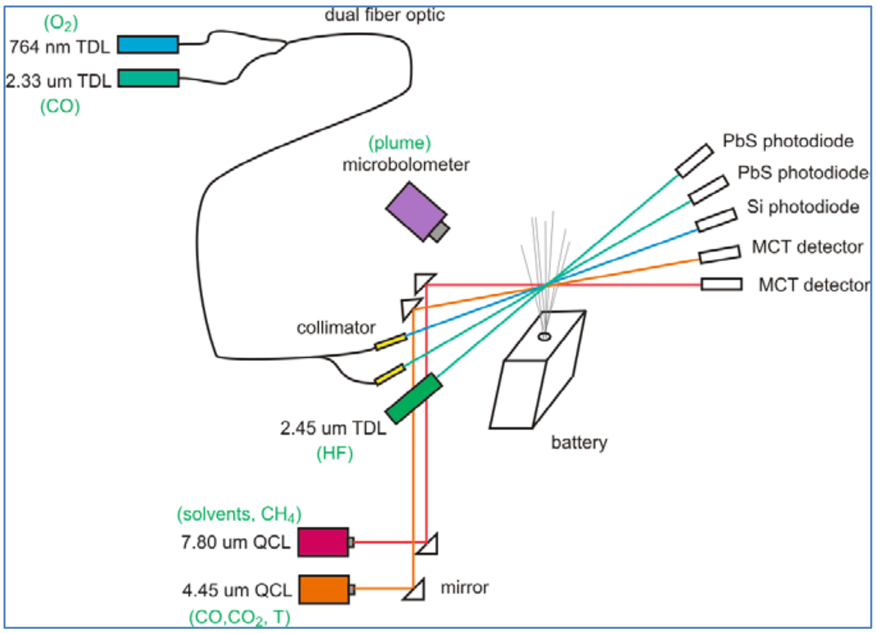
The wide range of chemistries and operating conditions required for grid-scale storage presents a significant challenge for safety R&D. The longer life requirements and wider range of uses for storage require a better understanding of degradation and end of life failures under normal operating and abuse conditions. The size of batteries also necessitates a stronger reliance on modeling. Multi-scale models for understanding thermal runaway, and fire propagation; whether originated in the chemistry, the electronics, or external to the system; have not been developed.

Currently gap areas for stationary energy storage exist from materials research and modeling through system life considerations such as operation and maintenance.

5.7.2 Materials science R&D

Materials safety can be validated through research. For example, in vehicle storage combustion research, facilities test with IR absorption the gas evolution and release in vented batteries as illustrated in Figure 4.

Figure 4. Experimental Setup of Gas Evolution and Release with Infrared Absorption



Opportunities are found in combining energy storage and power electronics safety and reliability testing from the cell to module levels. This could include projects to utilize on-line spread spectrum time domain reflectometry technique to determine the state of health of Wide Band Gap devices.[58] The amount of degradation depends on a number of factors including junction temperature, voltage and current stress, and duty cycle. Preliminary investigation will also be made for electrochemical systems to determine state of health. Furthermore, the thorough analysis and evaluation of abuse tolerance of energy storage systems including power electronics one may assess the tolerance of energy storage systems and engineering protections to short

[58] Ojeda, Juan. "Ultra-Wideband Technology and Test Solutions." Tektronix. 2007. http://www.afc-ingenieros.com/uploads/Afc/InfoTecn/RTSA/pdf/14%20Ultra-Wideband%20Technology%20and%20Test%20Solutions%20-%20AFC.pdf

circuit abuse, cell-to-cell failure propagation of the module and system level, and the severity of energy storage failure. Modeling the propagation of failed systems would be key to such work.

5.7.3. Engineering controls and system design

Currently the monitoring needs of batteries, as well as effectiveness of means to separate battery cells and modules, or various fire suppression systems and techniques in systems have not been studied extensively. Individual companies and installations have relied on past experience in designing these systems. For example: Na battery installations have focused on mitigating the potential impact of the high operating temperature, Pb-acid batteries has focused on controlling failures associated with hydrogen build up, while in technologies that don't use electrochemistry like flywheels, have focused on mechanical concerns such as run-out and high temperature, or change in chamber pressure. Detailed testing and modeling are required to fully understand the needs in system monitoring and containment of failure propagation. Rigorous design of safety features that adequately address potential failures are also still needed in most technology areas. Current efforts have widely focused on monitoring cell and module level voltages in addition to the thermal environment; however the tolerances for safe operation are not known for these systems. Further development efforts are needed to help manufacturers and installers understand the appropriate level of monitoring in order to safely operate a system and prevent failure resulting from internal short circuits, latent manufacturing defects or abused batteries from propagating to the full system.

5.7.4 Testing and analysis

Testing methodologies in the EV space are well established with respect to electrical, mechanical and environmental testing (Table 2). These efforts have focused on lithium ion technology and have not been established for most other electrochemical or mechanical storage technologies. New EV tests in failure propagation are of significant relevance to the grid storage space and must be applied to grid relevant technologies.

Table 3. Tests under Development for Specific Technologies

Technology	Tests under development
Batteries	Failure propagation Internal short circuit (non-impact test) Ignition/flammability IR absorption diagnostics Separator testing
Flywheel	Design margins in stress modulus Safety margins in containment Health monitoring and fault protection

5.7.5 Modeling

The size and cost of grid-scale storage system make it prohibitive to test full-scale systems, modeling can play a critical role in improved safety. System scale modeling efforts combined with experimental R&D cell/pack level validation can lead to improved designs for safe operation of larger systems. Cell level modeling can help gain a deeper understanding of batteries with respect to abuse tolerance and failure. These models must identify and account for: faster side reactions at increased temperature to prevent thermal runaway, increasing resistance at lower ambient temperature operation to capture the higher heat generation due to higher internal resistances. Temperature modeling can also account for the correlation between temperature and: dendrite growth, reaction rates, and cell degradation.

While EV safety research incorporating modeling has made some significant strides for the battery/pack level, system level installations may benefit mostly from the highly sophisticated modeling of fire containment within buildings developed for nuclear weapons. These models have over a decade of development into the detailed electrochemical, mechanical, and thermal properties and may be highly applicable to grid storage systems.

5.7.6 Fire suppression

Large-scale energy storage systems can mitigate risk of loss by isolating parts of a system in different transportation containers, or using materials or assemblies to section off batteries.

Most current systems have automated and manually triggered fire suppression systems within the enclosure but have limited knowledge if such suppression systems will be useful in the event of fire. Further work on fire dynamic simulations are needed to predict the size, scope and consequences of battery fires and the potential for propagation to the next enclosure. The information from kWh and MWh simulations can be used to design both the energy storage and the fire suppression systems. These efforts must be used to gain a better understanding of what containment measures are effective and economically viable.

The interactions between fire suppressants and system chemistries must be fully understood to determine the effectiveness of fire suppression. Key variables include the: volume of suppressant required, rate of suppressant release, and distribution of suppressants. Basic assumptions about electrochemical safety have not been elucidated, for example it is not even clear whether a battery fire is of higher consequence than other types of fires, and if so at what scale this is of concern. This is a very open area of research that needs quantitative findings in order to inform the industry.

The National Fire Protection Association (NFPA) has provided a questionnaire regarding suppressants for vehicle batteries.
Tactics for suppression of fires involving electric-drive vehicle (EDV) batteries:

a. How effective is water as a suppressant for large battery fires?
b. Are there projectile hazards?
c. How long must suppression efforts be conducted to place the fire under control and then fully extinguish it?
d. What level of resources will be needed to support these fire suppression efforts? 1
e. Is there a need for extended suppression efforts?
f. What are the indicators for instances where the fire service should allow a large battery pack to burn rather than attempt suppression?[59]

A suppression test was set up and fire, smoke and off-gassing were observed. Recommendations and future work identified included:

[59] "Best Practices for Emergency Response to Incidents Involving Electric Vehicles Battery Hazards." The Fire Protection Research Foundation. June 2013.

- Full-scale fire suppression testing of actual consumer EDVs to evaluate access issues in water application strategies in specific vehicle fire scenarios.
- Full-scale fire suppression testing of actual consumer EDVs to evaluate access issues in water application strategies in collision scenarios.
- Full-scale fire suppression testing of actual consumer EDVs to evaluate shock hazards when the entire vehicle electrical distribution system is present and possibly energized.
- Full-scale fire suppression testing of EDVs using cell formats different from those tested in this test series, such as 18650s.
- Free burn full-scale EDV fires to compare and contrast the advantages and disadvantages of letting EV fires burn out rather than suppressing.
- Evaluation of novel or alternate nozzle designs that may allow direct application of water to EDV batteries located below the vehicle underbody assembly.
- Determine the effectiveness of various water additives that may accelerate the cooling/extinguishment process.
- Conduct additional full-scale tests to evaluate the total water flow rates necessary to achieve extinguishment using new firefighter tactics, such as constant water application or a two hose line suppression team.

NFPA 13, *Standard for the Installation of Sprinkler Systems,*[60] does not contain specific sprinkler installation recommendations or protection requirements for Li-ion batteries. Reports and literature on suppressants universally recommended the use of water.[61] However, the quantity of water needed for a battery fire is large: 275-2639 gallons for a 40 kWh EV sized Li-ion battery pack. This is higher than recommended for internal combustion engine (ICE) vehicle fires. The NFPA report did not actually compare battery to a hydrocarbon fire in their experimental work on fire suppressants and was inconclusive as to the adequacy of a water sprinkler suppressant approach. To make use of previous studies of fire suppression, future R&D efforts should investigate identifying equivalencies of battery to fuel or other studied materials.

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[60] "NFPA 13: Installation of Sprinkler Systems and Handbook Set" NFPA Catalog. 2013.

[61] "Best Practices for Emergency Response to Incidents Involving Electric Vehicles Battery Hazards." The Fire Protection Research Foundation. June 2013.

5.8 Summary

Science-based safety validation techniques for an entire energy storage system are critical as the deployments of energy storage systems expand. These techniques are currently based on previous industry knowledge and experience with energy storage for vehicles, as well as experience with grid-scale Pb-acid batteries. Now, they must be broadened to encompass grid-scale systems. The major hurtle to this expansion is encompassing both much broader range in scale stationary storage systems, as well as the much broader range of technologies. Furthermore, the larger scale of stationary storage over EV storage necessitates the consideration of a wider range of concerns, beyond the storage device. This includes areas such as power electronics and fire suppression. The required work to develop validation is significant. As progress is made in understanding validation through experiment and modeling, these evidence-based results can feed into codes, regulations and standards, and can inform manufacturers and customers of stationary storage solutions to improve the safety of deployed systems.

6.0 Incident Preparedness

As with any large-scale deployed technology, there are risks that unintended events could result in a safety incident, exposing life, the environment and critical infrastructure at risk. Therefore, it is critical to develop an understanding of the possible failure modes of the systems and create plans to mitigate the potential for and the risk of these events as much as possible. Additionally, the scope of the incident preparedness for these systems must extend past the immediate workers at the facility to include first and second responders, as well as those in the surrounding area.

6.1 Current Conditions

Today's Fire Service is frequently being considered "All Risk" in terms of their response service levels. This means that first responders must be equipped and ready to respond to a vast array of different types of events, with the majority of emergency responses divided into the following categories:

1. Medical emergencies
2. Hazardous material releases
3. Fires of various origins
4. Weather-related incidents

5. Industrial and manufacturing incidents
6. Utility (electrical & gas) incidents – ESS falls into this category, regardless of utility, commercial, or residential application.
7. Investigation of system troubles

Whenever possible, First Responders create Risk Profiles and Incident Action Plans to manage the risks associated with an incident at a facility or residence. These plans assist in real-time risk managing utilizing the following incident priorities: life, incident mitigation, and property and environmental protection, and commonly use the following guideline: "We will risk a life to save a life. We will risk very little, in a calculated manner, to save savable property. We will risk nothing for what is already lost." [62] These plans help the first responders identify and understand the unique challenges associated with responses to specific sites, and allow them to be equipped to efficiently structure a response. However, the education and training currently provided to first responders is limited. As a result, response teams must craft incident response plans with little to no background knowledge about the system.

Emergency responses to manufacturing, industrial or utility incidences are typically considered low-frequency, high-risk occurrences in most fire departments. Though these events rarely occur, they carry the potential of high loss to first responders and the facility. This risk profile typically results in a cautious approach with a commensurately increased property loss. If first responders are aware of all the factors that will impact the risk profile of the incident before the incident occurs, the response will be faster and more effective with a commensurate decrease in loss. By contrast, medical emergencies are considered high frequency, low risk to the responder. First responders are better equipped to respond to the high frequency, low risk emergencies as a result of a thorough understanding of the risk and extensive training for these events. An additional complication is that the risk profile during an incident can continually evolve and it is imperative to determine if mitigation actions are consistent with the changing risks and benefits. For example, an ESS technician suffering a medical emergency while performing work on an ESS requiring responders to enter the battery hazard area to access and treat the technician.

[62] "Rules of Engagement: Adopt the Rules as Standard Operating Procedures." International Association of Fire Chiefs. April 1, 2013. http://www.iafc.org/onScene/article.cfm?ItemNumber=6735

Currently, fire departments do not categorize ESS as stand-alone infrastructure capable of causing safety incidents independent of the systems that they support. Instead, fire departments categorize grid ESS as back-up power systems such as uninterruptible power supplies (UPS) for commercial, utility, communications and defense settings, or as PV battery-backed systems for on, or off-grid residential applications. This categorization results in limited awareness of ESS and their potential risks, and thus the optimal responses to incidents. This categorization of energy storage systems as merely back-up power systems also results in the treatment of ESS as peripheral to the risk management tools.

There is also a diverse array of stakeholders invested in each energy storage system installation, for which an incident represents a potential risk, be that financial or to their health. For residential or community based systems, these parties include the homeowner and occupants of the residence and surrounding residence, the utility, and the manufacturer of the photovoltaic system to which the energy storage system is often coupled. In these cases, the top concerns of the fire department are the occupants, limiting the spread of the incident to neighboring structures, and mitigating remaining safety hazards. In contrast, the fire department must account for a very different set of stakeholders when responding to an incident at an industrial location. In this case, the risk of loss of human life is typically limited to potential system operators and the incident response plans are centered on containing the incident for the least consequence possible to the facility and community. In these cases, the system operators are often better trained, the hazards are better marked and there is often fire suppression capability built into the facility. Facility operators must be able to operate under a unified incident management system to ensure responders are aware of these safety systems and utilize them appropriately. This enables the first responders to more effectively limit damage to these typically high-value facilities.

6.2 Incident Preparedness

Incident preparedness activities can be divided into two categories: engineered controls and administrative controls. Administrative controls include activities such as pre-planning for an incident, codes and standards, and risk management tools. Engineered controls include aspects of the system and its installation such as fire suppression, storage system design, and fail-safes.

6.2.1 Engineered controls

The first step in ensuring safety of any system is to ensure that the system is designed to the highest possible level of safety. As previously discussed, the engineering of safety into a system must start at the materials level and be designed all the way through to deployment. For mature technologies, the methods used to ensure safety of the materials used and systems design are written into the CSRs where they can guide the design, manufacture, and deployment of the storage system. However, for new technologies such as grid-scale energy storage, the CSRs are not fully codified.

Fixed facilities may have the added benefit of fire suppression systems, central station alarm monitoring, emergency power-off systems, site access control, ventilation systems, and on-site facilities or trained engineering staff. Challenges include the increased commodity storage, R&D complication issues due to experimental processes and/or procedures, and fire service access issues. The staffing model of the local fire department, available water supply, and level of ES awareness possessed by the responders can either positively or negatively impact any of the aforementioned challenges. Current fixed-facility suppression systems utilize extinguishing agents that typically include water mist, dry chemical, CO2, or other inert gas agents.

6.2.2 Administrative controls

Two main components of the administrative controls for energy storage system safety are the emergency preparedness plans and the CSR. The former guides first responders as to what actions to take in an emergency, and the latter dictates the facility signage, processes and procedures.

Because of the low frequency of energy storage incidents, the wide variety systems sizes and technologies, and deployment options there is a need to develop comprehensive emergency preparedness plans. These plans must begin with what is commonly referred to as a Community Risk Assessment (CRA) to identify potential emergency scenarios. The scenarios addressed in the CRA must be based on the energy storage system characteristics and application space, and must comply with OSHA requirements (Appendix A). The property owner/occupant develops several incident-specific response plans, based on the CRA. These plans identify performance objectives and action steps to support the local risks and incident scenarios and can include fire pre-incident plans created by first-response organizations. The pre-incident plans are typically based on several factors: fire department resources, unique or higher risk properties from an occupancy classification, life hazard, and special event. These pre-incident plans can include a casual building familiarization tour to a formal document complete with maps, fire control system locations, utility connections, high hazard contents, and building contact information. None of these elements by themselves should be considered adequate pre-incident planning, as all of them are fundamental requirements of pre-incident planning.

The CRA must take into account the diversity in deployment environments, applications, and interested parties surrounding the energy storage system (ESS). As previously discussed, an ESS used in conjunction with a residential PV installation has different risks than an energy storage system used at an industrial location. The risk management for the residential ESS application must be addressed with the occupancy load in mind; the risk of negative effects to human life is much higher. The physical location of a residential ESS must also be considered in order to best plan for strategies to extinguish a fire while also protecting human life. The risk management for the remote, industrial ESS installation must include the specific hazards and challenges of the physical location. For example, if the installation is on a hill with impassable roads, fire apparatus may not be able to reach the fire, thus increasing the risk of damage to surrounding property and/or land. OSHA requires an Incident Response Plan, or Emergency Action Plan (*29 CFR 1910.38*) when the following primary tasks are involved:

- Proper identification of specific hazard, i.e., fire, spill, emergency medical services (EMS) incident
- Proper identification of energized electrical equipment
- Rapid identification of available disconnects - requires clear, consistent marking with permanent labeling
- Liaison with responsible party, i.e., facility maintenance personnel with specific building systems knowledge
- Determination of resource requirements (an ongoing assessment based on scope and type of incident)

The energy storage industry is rapidly expanding due to market pressures. This expansion is surpassing both the updating of current CSR and development of new CSR needed for determining what is and is not safe and enabling first responders to craft pertinent pre-incident plans. Standards exist for mature ESS such as Lead-acid, NiCd, and NiMH, covering the technical features and testing of the system and its integration with other systems and buildings/facilities. For other storage technologies, however, less CSR guidance is provided. No general, technology-independent standard for ESS integration into a utility or a stand-alone grid has yet been developed. There is an International Electrotechnical Commission (IEC) standard planned for rechargeable batteries of any chemistry.[63] This IEC standard potentially could be used as a template for standards needed in North America, but currently is not significantly useful to American first responders.

6.3 Incident Response

Incident responses with standard equipment are tailored to the specific needs of the incident type and location, whether it's two "pumper" engines and a "ladder" truck with two to four personnel, plus a Battalion Chief to act as Incident Commander, for a total of nine to thirteen personnel responding to an injury/accident, or a structure fire that requires five engines, two trucks, and two Battalion Chiefs for a total of seventeen to thirty personnel. With each additional "alarm" struck will send another two to three "pumper" engines and a "ladder" truck. In all of these cases, the incident response personnel typically arrive on scene with only standard equipment. This equipment is guided by various NFPA standards for equipment on each apparatus, personal protective equipment (PPE), and other rescue tools. In responding to an ESS incident, the fire service seldom incorporates equipment specialized for electrical incidents. At best, many departments have a non-contact AC current detector that is used to detect AC current in structures, wires down-type incidents, or vehicles into energized equipment. Fire departments do not typically provide or maintain electrical PPE.

With this background in mind, a number of unique challenges must be considered in developing responses to any energy storage incident. In particular, difficulties securing energized electrical components can present significant safety challenges for fire service personnel. Typically, the primary tasks are to isolate power to the affected areas, contain spills, access and rescue possible victims, and limit access to the hazard area. The highest priority is given to actions that support

[63] http://www.iec.ch/whitepaper/pdf/iecWP-energystorage-LR-en.pdf

locating endangered persons and removing them to safety with the least possible risk to responders. Where the rescue of victims continues until it is either accomplished or determined that there are no survivors or the risk to responders is too great. Industrial fires can be quite dangerous depending on structure occupancy, i.e. the contents, process, and personnel inside. Water may be used from a safe distance on larger fires that have extended beyond the original equipment or area of origin, or which are threatening nearby exposures; however, determination of “safe” distance has been little researched by the fire service scientific community. In 2011, the safety testing and certification organization Underwriters Laboratories (UL), funded by the Federal Emergency Management Agency (FEMA), explored safe distances up to 1000Vdc for the purposes of water application on photovoltaic systems,[64] but there has been little education within the fire service on voltages above that level.

6.4 Gap Areas

The gaps in incident response pertaining to ESS are primarily a result of these systems being in early stages of deployment. As ESS begins to proliferate in residential, commercial and industrial settings, the probability of an incident increases and this knowledge gap must be addressed. Specifically, five areas have been identified as critical gaps:

1. Fire suppression and protection systems
2. Commodity classification
3. Verification and control of stored energy
4. Post-incident response and recovery
5. First responder awareness and response practices

6.4.1 Fire suppression and protection systems

Each ESS installation is guided by application of existing CSR that may not reflect the unique and varied chemistries in use. Fire-suppressant selection should be based on the efficacy of specific materials and needed quantities on site based on appropriate and representative testing, conducted in consultation with risk managers, fire protection engineers, and others, as well as alignment with existing codes and standards. For example, non-halogenated inert gas discharge systems may not be adequate for thermally unstable oxide chemistries, as they generate oxides in

[64] http://www.ul.com/global/documents/offerings/industries/buildingmaterials/fireservice/PV-FF_SafetyFinalReport.pdf

the process of heating, which may lead to combustion in oxygen deficient atmospheres. Ventilation requirements imposed by some Authorities Having Jurisdiction (AHJs) may work against the efficacy of these gaseous suppression agents. Similarly, water-based sprinkler systems may not prove effective for dissipating heat dissipation in large-scale commodity storage of similar chemistries. Therefore, additional research is needed to provide data on which to base proper agent selection for the occupancy and commodity, and to establish standards that reflect the variety of chemistries and their combustion profile.

6.4.2 Commodity classification

Current commodity classification systems used in fire sprinkler design (NFPA 13-Standard for Installation of Sprinkler Systems) do not have a classification for lithium or flow batteries. This is problematic, as the fire hazard may be significantly higher depending on the chemicals involved and will likely result in ineffective or inaccurate fire sprinkler coverage. Additionally, thermal decomposition of electrolytes may produce flammable gasses that present explosion risks. Better understanding of these gases and the combustion process of the overall battery chemistry is needed to identify adequate fire protection systems.

6.4.3 Verification and control of stored energy

Severe energy storage system damage resulting from fire, earthquake, or significant mechanical damage may require complete discharge, or neutralization of the chemistry, to facilitate safe handling of components. Though the deployment of PV currently exceeds that of ESS, there is still a lack of a clear response procedure to de-energize distributed PV generation in the field. Fire fighters typically rely on the local utility to secure supply-side power to facilities. In the case of small residential or commercial PV, the utility is not able to assist because the system is on the owner side of the meter, which presents a problem for securing a 600Vdc rooftop array. Identifying the PV integrators responsible for installation may not be possible, and other installers may be hesitant to assume any liability for a system they did not install. This leaves a vacuum for the safe, complete overhaul of a damaged structure with PV. Similarly, ESS faces the complication of unclear resources for assistance and the inabilities of many first responders to knowledgably verify that the ESS is discharged or de-energized. The need for response procedure for distributed PV may begin to be positively impacted by CSR, as there is proposed language for consideration by the NEC in January 2015 that addresses rapid shutdown of PV systems. However, this gap area must be more thoroughly addressed to ensure complete procedures that limit the risk to life and property.

6.4.4 Post-incident response and recovery

Thermal damage to ESS chemistries and components presents unique challenges to the fire service community, building owners, and insurers. As evidenced in full-scale testing of EV battery fires, fire suppression required more water than anticipated, and significantly more in some cases.[65] Additionally, confirming that the fire was completely extinguished was difficult due to the containment housings of EV batteries that can mask continued thermal reaction within undamaged cells. In one of the tests performed by Exponent, Inc., one battery reignited after being involved in a full-scale fire test some 22 hours post-extinguishment; in another case, an EV experienced a subsequent re-ignition 3 weeks post-crash testing.[66]

The results of the Fire Protection Research Foundation (FPRF) report on electric vehicle (EV) battery fires corroborate the additional need to educate "secondary responders" such a tow operators, repair facilities, and storage yards when damaged hybrid and EV batteries are on their properties. This need also exists in the grid energy storage context, where cleanup, salvage and recycling are all potentially components of a response to an incident.

6.4.5 First responder awareness and response practices

For the responder community, incident preparedness necessitates varying levels of education. The first responders in the U.S. fire service have divergent experience levels, career and volunteer staffing levels, and varying physical resources. Therefore, no singular training model can successfully engage the entire community. Fortunately, many models of fire service education, from instructor-led classes, to web based modules and webinars, print media, and conference presentations, have proven successful in reaching the fire-fighting community on issues such as incident response to electric vehicle accidents. Both UL and NFPA have received funding for research of responder tactics and hazards for emerging technologies and leveraged them into training curriculum. In the case of electric vehicle safety education, in 2009 NFPA

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[65] http://www.nfpa.org/research/fire-protection-research-foundation/reports-and-proceedings/hazardous-materials/other-hazards/lithium-ion-batteries-hazard-and-use-assessment-ph-iib

[66] Long, Jr., R. Thomas; Blum, Andrew F.; Bress, Thomas J.; Cotts, Benjamin R.T. "Best Practices for Emergency Response to Incidents Involving Electric Vehicles Battery Hazards: A Report on Full-Scale Testing Results." Exponent, Inc. June 2013.

received a $4.4M grant through FEMA and DOE to support a nationwide education outreach program focused on first responders.[67] This program was delivered in all fifty states as a train-the-trainer program. It has since been developed as an online program managed by the NFPA, and has been viewed by tens of thousands of firefighters worldwide.

7.0 Safety Documentation

The research and development of innovative energy storage technologies is constantly advancing new technologies with a commensurate increase in the number and types of systems deployed. However, the safety documentation used to standardize the new technologies and serve as a basis for regulating the deployments of energy storage through CSR is lagging far behind this constant innovation and, as a result, is ineffective in validating the safety of each deployment and informing needed CSR criteria. To be effective, safety determination, documentation and verification must be standardized and specific to each chemistry, component, module, and deployment environment of each type of system. This standardization and relevance will ensure economically viable, validated safe deployments of increasingly innovative energy storage technologies. In order to ensure continued relevance, CSR must be actively updated according to innovations within the research and development of all systems. Ideally, determining what is and is not safe and the documentation associated with validating safety will enable the deployment of safe energy storage systems as the industry captures and communicates the best practices for engineered safety from components to full systems. The following discussion will explain the current risks in energy storage deployment that must be addressed through safety determination, documentation, and verification, and identify areas that need to be improved towards this end.

Crafting effective safety metrics and criteria requires recognition of two interconnected components, i.e., the myriad of stakeholders involved in the process and the complex and differing documentation required for each component, module, system, and deployment environment. A thorough safety determination involves standards that could apply to every step and stakeholder along the value chain, including first response. However, standards are merely a

[67] www.evsafetytraining.org

tool in the regulatory spectrum that may or may not be adopted, required, or used to establish acceptable practice. Each type of classification carries with it different legal implications for different stakeholder groups. Federal, state and local agencies, for instance, may be involved in the development, adoption and enforcement of building construction regulations, as well as safety, environmental, and occupational safety rules, all of which have legal implications. Some standards have been codified and are administered by regulators, whereas others, including protocols, guidelines and other documents, have not been codified and are merely guidelines for system manufacturers and owners. Standards that have not been adopted as mandatory, however, may have legal implications, as in cases of negligence when standards may be entered into evidence.

Standards complexity also arises from diverse regulatory requirements for every component of the ES system. Additionally, the components of a system may have individual standards to satisfy, but similar documentation may not exist for the systems as operational entities. Manufacturers of the individual components possess clear guidance, but system manufacturers and owners of an installed, operational system may lack such clarity. The safety regulations required may also differ between federal, state, and local agencies or utilities, thereby complicating the process needed for one manufacturer to sell its system in different states, to different buyers.

Federal, state, and local regulations, including those governing safety, affect every stakeholder, up and down the value chain. On the Federal level, the question with respect to regulation has to do with cost recovery for the utility, i.e., is energy storage generation or distribution? The Federal Energy Regulatory Commission (FERC) does not regulate power generation, but it does regulate the transmission, or distribution, of electricity in interstate commerce. To the extent that ES is considered generation, the utility cannot recover the associated costs through its rate base and be reimbursed for such costs by its customers. However, to the extent that ES is considered an ancillary service to transmission services provided by the utility, the utility can recover those costs through its rate base. In addition, ES is being evaluated and considered in the various Independent System Operators (ISOs) and Regional Transmission Organizations (RTOs).

On the state level, each state regulates ES differently. Several states have recognized the significance of ES and have addressed its role in power supplies, but most have not. For example, California has mandated that the three major investor-owned utilities in California (Pacific Gas & Electric, Southern California Edison, and San Diego Gas & Electric) incorporate energy storage into their state-mandated Renewable Portfolio Standards. Similar support for ESS also exists in Hawaii, Texas and New York. Other states are reviewing ES in the context of pilot or experimental programs. This regulatory gap between the states probably will narrow as the industry matures and market participants push the state to recognize the industry.

Ultimately, the goal is to standardize the safety documentation that will guide every step of the Energy Storage system process, from the manufacturing of components, to the structuring of entire systems, to system deployment and installation. This guidance is crucial to ensuring the validation of safe energy storage systems, and must be standardized and consistent on the federal, state, and municipal levels, and relevant to every battery chemistry and deployment environment. The following discussion gives an overview of codes, standards and regulations (CSR), and highlights the liability risks that are presented if CSR are disregarded or non-existent.

7.1 Overview of the CSR Deployment Process and Involved Stakeholders[68]

Deployment involves the processes associated with the adoption of model codes and standards as laws, rules, or regulations and the entities involved in that process. It also covers how compliance is documented and verified through processes associated with conformity assessment.

Any entity, whether a person, corporation, insurance carrier or utility, federal, state or local legislative body or governmental agency, can adopt model CSR. The act of adoption through a law, rule, regulation, statute, contract specification, tariff or any other vehicle is intended to ensure that the model codes and standards developed in the voluntary sector, or directly developed by the adopting entity, are required to be satisfied and that a basis for enforcement will ensure compliance. While federal, state, and local governments and other adopting entities have the authority to develop CSR, most adopt those developed in the voluntary sector at the national level with amendments, additions, and deletions to address any specific needs of theirs that are not addressed in those documents.

[68] Conover, David R. "Overview of Development and Deployment of Codes, Standards and Regulations Affecting Energy Storage System Safety in the U.S." Pacific Northwest National Laboratory. August 2014.

The federal government does not generally have the authority to mandate the adoption of CSR by state or local governments, although federal agencies can influence what is adopted through other means such as the availability of federal funding. Aside from buildings owned or leased by federal agencies and a few instances where the federal government has preemptive authority,[69] resulting in Congress or federal agencies adopting specific CSR, state and local regulations will apply to the built environment, including an ESS installation. For ESS on the grid side of the meter, equipment and buildings owned or operated by the utility are covered by what the utility adopts.

Once adopted, the model codes and standards are law; legal authority is granted by legislative bodies or regulatory agencies for their implementation and enforcement (e.g. conformity assessment). When adopted by utilities, insurance or corporate entities through tariffs, policies, specifications, contracts, or other legal documents, then what is adopted may apply over and above government adoptions, or will apply where no laws or regulations have been adopted or the government lacks the authority to adopt. The responsibility for documenting compliance with what is adopted rests with various private sector entities—manufacturers, builders, designers, product specifiers, contractors, building owners, utilities and others—involved in the design, construction, operation, use and demolition or decommissioning of what is regulated. The responsibility for determining and adjudging compliance rests with those representing the adopting authorities and is carried out based on an assessment of the documentation provided, including inspections, against what has been adopted. With respect to ESS, the manufacturer of the system components would be responsible for documenting component compliance; the system manufacturer for documenting system compliance and a builder, engineer or record or contractor responsible for documenting that the system installation is compliant. After an ESS installation is approved,[70] those engaged with its operation and maintenance would also be responsible for compliance with any applicable CSR, including those applicable to the repair, alteration, relocation or renovation of an existing ESS. Those verifying compliance (e.g. AHJs that enforce the adopted CSR) would include governmental agencies, utilities, insurance carriers

[69] Examples are product labeling (FTC), appliance efficiency (DOE) and manufactured housing construction (HUD).
[70] Approval is considered verification of compliance by the relevant Agencies Having Jurisdiction (AHJs) with what is adopted.

and others who adopted the CSR and made them applicable to the ESS components, system, system installation and operation and maintenance of the system.

7.1.1 Impacts of CSR on realizing ESS market opportunities[71]

The DOE/EPRI 2013 Electricity Storage Handbook indicates that the biggest challenges hindering adoption of energy storage technology are cost, the ability to deploy ESS, and lack of standards. [72] Standards and codes—or the lack thereof—have a direct impact on the cost of an ESS and its installation, in terms of material and manpower. Additionally, administrative burdens and time-to-approval issues affect technology deployment and increase costs. The absence of criteria upon which to evaluate technology performance, reliability and safety leaves those seeking to move ESS into the market and those responsible for public safety, with little on which to base a determination that the system and its installation are "safe." Until existing CSR are updated and/or new CSR are developed that specifically address the range of ESS technologies and installations and those CSR are adopted, it will be difficult to document what is safe and determine what can be approved in a uniform and timely manner. In some instances, the lack of specifics limits progress until appropriate CSR are available; in others, "outdated" CSR can be applied conservatively to the technology could affect the cost of the installation or limit its application.

Though CSR must be updated specifically to address new ESS technology and ESS applications, CSR still currently provide a path to documenting and validating compliance, assuming that what is proposed is no more hazardous nor less safe and performs at least as well as other technologies that are specifically covered by existing CSR. While affording approval, this path requires criteria for determining and documenting and "equivalent safety" by each entity that enforces the adopted CSR. This type of approval process can result in a "custom" documentation package for each jurisdiction (approval authority) where an ESS is desired on the customer side of the meter or each utility when the ESS is on the grid side.[73] In addition, those AHJs may not be

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[71] Conover, David R. "Overview of Development and Deployment of Codes, Standards and Regulations Affecting Energy Storage System Safety in the U.S." Pacific Northwest National Laboratory. August 2014.

[72] Akhil, Abbas; et al. "DOE/EPRI 2013 Electricity Storage Handbook in Collaboration with NRECA." Sandia National Laboratories. July 2013.

[73] Those responsible for ESS approval (whether federal, state or local government, utilities, insurance carriers or others) can be classified as AHJs.

inclined to allow this path to compliance because they would have to develop those criteria, spend time assessing the evidence that documents equivalent performance, and then actually sign off that the installation is safe on that basis. Clearly, having updated and specific CSR to document and validate ESS safety is preferable and should be instituted soon.

In the immediate absence of updated CSR, a performance path to document and validate compliance, which can be facilitated at the national level through the development of formal acceptance criteria (pre-standards, protocols, or bench standards). An accredited third-party agency or entity could validate the safety of an ESS based on documented performance equivalent to that required by current CSR. In that case, AHJs could rely on those acceptance criteria and the assessment by an accredited third party in considering whether to approve an ESS installation, instead of making individual determinations. While a good short-term solution, even if facilitated through a nationally recognized AHJ process as an indication of CSR compliance, this scenario would require additional time and resources compared with securing approval based on compliance with ESS-specific CSR that specifically address the range of ESS available now and through continued updating of CSR those that will be developed in the future.

7.1.2 The role of research, analysis and documentation in the development and deployment of CSR[74]

To be relevant and useful to the safe deployment of grid-scale energy storage systems, CSR must incorporate best practices and lessons learned from innovation validation techniques for each system. However, a standards development organization (SDO) will find it difficult to approve the development of or reference to requirements or test methods unless some basis for their validity exists. Without documentation, it is difficult to secure approval to circulate for public review and comment on proposed criteria for CSR or to move through the remaining steps in standards and model code development. In most cases, the need for basis and documentation for the criteria will guide the development of the CSR language to be considered by an SDO, although it is not unusual to find these proposals with “soft” technical justification. Beyond development, if criteria appear controversial or marginally supported they are likely to be deleted or significantly revised when the CSR is considered for adoption.

[74] Conover, David R. “Overview of Development and Deployment of Codes, Standards and Regulations Affecting Energy Storage System Safety in the U.S.” Pacific Northwest National Laboratory. August 2014.

Consider an ESS that is proposed for internal building use. The impact of any chemicals that comprise the system must be considered because building and fire codes limit the amount of chemical storage within buildings. Such limits could prohibit or significantly alter the intended installation as to building location, separate the system into smaller modules, or change the use group of the associated spaces in the building thereby imposing additional new requirements. In the short term, if existing CSR criteria are applied to an ESS installation inside a building, research, analysis and documentation may be required to address their inappropriate application to the system. In the long term, if changes to the CSR are to be proposed, it will be necessary to document all aspects of installation safety based on research and experience with existing ESS installations. The resulting body of knowledge would facilitate more appropriate treatment of ESS by updating CSR based on substantiated information. A prepared ESS industry is better able to advocate for designation of its technology as safe and achieve the successful updating of CSR and deployment of ESS with a robust and solid body of research and safety-related documentation. Without that assurance, AHJs, who are integrally involved in development and deployment of CSR and whose sole mission is protecting public health and life safety, will be less likely to approve ESS installations because they will lack the needed guidance in the previously adopted CSR.

Of particular relevance is the entity (and whom that entity represents) that does the research, analysis and documentation. While an ESS manufacturer may conduct its own testing, analysis and other work to evaluate and document system safety for internal purposes, an accredited third party should conduct testing, analysis and other work intended for use in documenting the safety of and securing approval for the ESS. Ideally, the development of the documentation and supporting materials needed to update CSR will be conducted on behalf of the ESS industry by recognized third parties that focus on common goals, objectives, and issues. In turn, third-party study yields a robust, defensible, uniform and reasonable set of CSR for the industry to use in documenting and verifying ESS safety. In short, a team approach founded on a common and collective body of research and analysis is generally preferable to separate initiatives that propose single technology or manufacturer solutions to addressing ESS safety. Without a community-wide approach to updating CSR based on scientific validation techniques, every stakeholder is open to risk, as will be discussed, below.

7.2 Compliance with Land Use Permitting and Environmental Requirements

Governmental approvals and permits related to the siting, construction, development, operation, and grid integration of energy storage facilities can pose significant hurdles to the timely and cost effective implementation of any energy storage technology. The process for obtaining those approvals and permits can be difficult to navigate, particularly for newer technologies for which the environmental, health, and safety impacts may not be well documented or understood either by the agencies or the public. This section provides a brief introductory overview of key issues and risks that energy storage developers, investors, utilities, and others should understand. The discussion is not exhaustive, as risks vary in scope and significance from project to project and permitting requirements vary significantly between jurisdictions.

7.2.1 Overview of regulatory and litigation risks

Regulatory and litigation risks generally fall into two categories, which are often interrelated: delay and cost. At the far end of the spectrum, there is a risk that a permit or approval will be denied entirely, or revoked (temporarily or permanently) due to a violation or other unforeseen circumstances. While this worst-case scenario should be considered, it is more likely that the key risks will consist of significant delays and the imposition of unforeseen permitting conditions. The pace at which an application for a permit or approval moves through the regulatory process depends largely on a jurisdiction's land use regulations and environmental review process. The federal, state or local building regulatory process also affects customer-side installations. Significant delays can arise if an agency requests voluminous information and studies about the project, or if there are extended negotiations with staff over permit terms and conditions. Gaps in interagency coordination and the intervention or participation of third parties can also lead to delays. Finally, even if all required permits and approvals are secured, an opponent can file a lawsuit which could lead to an injunction that halts construction, inhibits financing, or otherwise imposes additional delay and cost.

The potential risks depend on a number of factors that will vary widely from project to project. Key factors to consider when assessing such permitting and litigation risks include the following: jurisdictions involved, the siting of the project on private or government-owned land, the physical size and footprint of the project, the presence of sensitive natural resources (such as wildlife, scenic views, watersheds, or prime agricultural land) or cultural resources on the site or within the vicinity, the type of technology and intensity of operations, opposition from neighboring land owners and public interest groups or other third parties, and pending or anticipated legislative and regulatory changes.

While it is not possible to eliminate risks entirely, strategies to reduce or mitigate risks can be developed for a particular project based on its unique circumstances. These may include early engagement with agencies and their staff, outreach to third parties that may be affected, siting the project away from sensitive resource areas, designing the project to limit its footprint, and mitigating environmental impacts. Energy storage systems that are co-located, or concurrently permitted, with generation facilities may be able to use or otherwise benefit from the permitting and environmental review that had been conducted for the generation facility, significantly streamlining the process. In addition, a proponent may be able to leverage federal, state, and local policies to promote energy storage that could help clear any potential roadblocks.

7.2.2 Time Considerations

Proponents of energy storage systems should allow sufficient time in the project schedule for the permitting and government approvals process, with appropriate contingencies for appeals and litigation. The time needed to obtain all required approvals ranges from several months to several years, depending on the layers of regulatory review involved and the balance of risk factors outlined above. Consideration should also be given to contractual deadlines for commencement of initial operations and service delivery.

7.2.3 Potential Permits and Approvals Required

Siting

As a threshold matter, the agencies involved and the approvals and consents required will be determined by the geographic location of the energy storage system. For example, facilities sited on federal land require federal approval (*e.g.*, a right-of-way authorization) that is subject to review under the National Environmental Policy Act (NEPA). If federal agency approval or funding is not required, an energy storage facility likely will be subject only to state or local environmental review, the scope and burden of which varies considerably between jurisdictions. Permitting risk may be reduced for energy storage systems that are co-located and/or concurrently permitted with generation facilities or that are sited in previously disturbed areas.

Construction/Development

In addition to siting factors, the type of ESS technology will also determine the agencies involved and the permits and approvals required. For example, some battery installations may have a minimal footprint that reduces or avoids impacts triggered by land disturbance, compared with pumped hydroelectric storage projects with large footprints.

Most permits and approvals required for the development of an energy storage system must be obtained prior to commencement of construction. Permits and approvals required for construction (including any conditions that must be satisfied) should be prioritized over other approvals that are not required until commencement of operations.

Depending on the jurisdiction, environmental impacts from the development of an energy storage system, including the construction process itself, generally need to be analyzed and, in many jurisdictions, mitigated. The impacts from energy storage systems vary by technology, but common impacts to consider include aesthetics, air quality, biological resources, cultural resources, hazards and hazardous materials, and water quality impacts. Agencies may impose conditions and mitigation measures that the project proponent must satisfy, or they may approve an alternative project location or design that has less environmental impacts.

Operation

Once construction is complete, the permits and approvals required for the operations phase are tailored to the type of technology and the inputs and outputs involved. For example, there are a host of rules and regulations at the federal, state, and local levels applicable to the generation, handling, and disposal of hazardous materials and waste. Air emissions, including greenhouse gases and criteria air pollutants, and water and wastewater discharges are also regulated at multiple levels of government. Permits and other rights may be required to procure resources and inputs necessary for operations, such as water rights. Depending on the type of technology and life expectancy of the facility, a decommissioning and site restoration plan may also be required, with accompanying financial assurances.

Grid Integration

In addition to the permits and approvals required for the energy storage system itself, other approvals likely will be required for the interconnection infrastructure that will integrate the storage system with the grid. Transmission, distribution, and interconnection facilities may be permitted as components of the energy storage system, as components of the energy generation facility, or separately as independent projects. Permits and environmental review for interconnection infrastructure may follow a separate regulatory track and timeline, particularly if the infrastructure will serve multiple facilities. Thus, regulatory and litigation risks for interconnection infrastructure should be evaluated independent of the energy storage system itself.

7.3 Legal Framework for Energy Storage System Safety

Energy storage technologies are subject to various federal, state, and local legal and regulatory requirements that are designed to protect workers, the public, and the environment from unreasonable risks. Because energy storage systems may reflect advancement in existing technology—such as solid state and flow batteries—or entirely new technologies, fitting these systems into the existing regulatory framework often poses a challenge to the energy storage industry. The following discussion introduces the main regulatory structures that are in place beyond CSR discussed above to address potential health and safety risks. Of course, this discussion provides only an overview, as risks will vary in scope and significance depending on the type of technology and scale of the system.

7.3.1 Workplace Safety and Training

The U.S. Occupational Health and Safety Administration (OSHA) and its state agency counterparts are the lead agencies that regulate workplace safety, including any workplace that produces or relies on energy storage technologies. The federal Occupational Health and Safety Act outline the regulatory framework applicable to all employers. In almost every state, the requirements of the Occupational Safety and Health Act are administered and enforced by the States pursuant to approved plans. The OSH Act requires almost all employers to develop an Illness and Injury Prevention Plan, or IIPP, which sets forth potential safety risks and develops standards for worker protections in order to prevent any “unreasonable risk of injury.” To develop an IIPP, employers are required to analyze workplace hazards and develop effective protocols to prevent them, which may include personal protective equipment, pre-employment training or certification, accident investigation, and emergency response procedures.

OSHA also develops specific worker safety standards for certain equipment and industries that are known to be particularly hazardous. For example, OSHA recently updated its 1972 standard that prescribes safety protocols for workers in the electric power, generation, and transmission and distribution industry. OSHA has also regulated potentially hazardous energy sources for many years through its “lockout-tagout” protocols that protect service workers who work with electrical equipment. Certain OSHA regulations may be applicable to “new” energy storage technologies, such as the OSHA standards for compressed gas and equipment.

For workplaces that contain highly technical systems, OSHA works with experts in national standard-setting organizations to develop appropriate standards for worker safety. For example, OSHA has worked with various organizations discussed in other parts of this paper. The National Fire Protection Association (NFPA), for example, has developed the National Electrical Code, an ANSI-approved United States standard for the safe installation of electrical wiring and equipment. The NFPA has also developed the Uniform Fire Code, which is an internationally accepted guidance for fire suppression technology that is incorporated into every state’s law. The Uniform Fire Code (UFC) has specific standards for stationary lead-acid battery systems, and NFPA is carefully studying lithium ion and more advanced batteries. Even without guidance for a particular technology, the UFC sets forth key principles to guide fire suppression practices.

Similarly, OSHA has worked with the Institute of Electrical and Electronics Engineers, which has developed operating and safety standards for the installation and maintenance of lead battery storage systems. Finally, OSHA refers to the standards used by Underwriters Labs, which provides internationally accepted life safety and performance certification for electrical components.

Even with ample regulatory guidance, the energy storage s sector should be aware of the processes that can identify potential safety hazards for a specific technology. OSHA provides guidance to industry on the recognized hazard analysis methodologies, including the basic Job Hazard Analysis, Failure Mode and Effect Analysis, and Hazard and Operability Study. However, one of the challenges facing the industry is how to analyze not only the failure of the individual component in a lab setting, but also the potential hazards presented by that failure in the specific use environment. Mitigation of the hazards associated with a single component may require facility redesign.

As with many high-technology employers, energy storage industry participants must be aware of the multiple sets of regulatory requirements as they relate to the various U.S. and international standards discussed herein, to ensure that their workplace environment reflects the most relevant applicable standards, and that employees are trained to work safely with energy storage technology.

7.3.2 Hazardous Materials Management

Both traditional and flow battery systems rely on electrode and electrolyte compounds that are composed of potentially hazardous chemicals. Employers who handle certain threshold quantities of hazardous materials are required to prepare and have available Safety Data Sheets (SDS) under the OSHA Hazard Communication Standard, to ensure employees understand the health and safety risks posed by workplace materials. Pursuant to the federal Emergency Response and Community Right to Know Act (EPCRA), employers must also submit an inventory of their hazardous chemicals to the State Emergency Response Commission, Local Emergency Preparedness Committee, and the local fire department annually.

While OSHA is the lead agency for workplace safety, the Environmental Protection Agency and federal environmental laws govern many aspects of hazardous material handling. In addition to EPCRA, the Resource Conservation and Recovery Act and its implementing regulations (as well as parallel state laws) have detailed regulations for the precautions necessary to prevent hazardous materials releases. Certain unanticipated releases of hazardous materials must be reported to the appropriate emergency response agencies—whether a release requires local, state, and/or federal reporting depends on the nature and quantity of the released material.

7.3.3 Catastrophic Accidents and Liability Risks

Market participants in the energy storage sector, and especially producers and marketers of energy storage technologies, should be prepared to address potential legal liabilities in the event of a catastrophic accident. An industrial accident that injures persons or property will be subject to the basic principles of tort liability, which varies by state. For example, if an explosion or fire causes personal injury or property damage, like any business, an energy storage company may be subject to liability to the extent that an injured party can establish the company's negligence in how it managed the process that led to the accident. In some jurisdictions, a company can be subject to strict (no-fault) liability, if the harmed party can establish that the company was engaged in an "ultrahazardous activity" (*i.e.*, an action or process so inherently dangerous that it cannot be made safe). Whether an activity is ultrahazardous is determined by case-specific analysis. If an injured party establishes that a company's conduct was "malicious, oppressive or in reckless disregard of a plaintiff's rights"—the precise language varies from state to state—he or she may be able to seek an award of punitive damages.

Injuries to workers caused by industrial accidents are covered by a state's workers compensation program, which is administered exclusively by that state. Employers are required by law to purchase workers' compensation benefits for employees or to self-insure for such benefits.

OSHA requires each employer's Illness and Injury Prevention Plan to include a procedure for investigating accidents; an accident that involves employee injury must be recorded by the employer, and if sufficiently serious (i.e. requiring hospitalization), it must also be reported to OSHA or the designated State agency. If the accident results in a fatality, catastrophe (hospitalization of three or more workers), or "incident of national significance" (a mass exposure/injury event), OSHA will conduct a mandatory investigation into the cause of the accident to determine whether a violation of OSHA safety and health standards occurred, and any effect the violation had on the accident. Following that investigation, OSHA may issue a finding of a violation, including proposed civil penalties. In rare instances where there is a "willful violation" of the OSHA standards, the matter may be referred to a federal prosecutor for criminal prosecution.

8.0 Implementation of Goals to Reach Desired End States

For any ESS, the achievement of the desired end-state will require a comprehensive technical and institutional initiative by a large and diverse group of stakeholders. Specifically, it will require the following activities:

- Establishment of a framework for risk assessment and management and the associated processes to evaluate and manage ESS technology risk at all stages of its life
- Technical research to a) characterize fundamental safety-related attributes of ESS technologies and b) address risk reduction ranging from alternative material sets for various technologies to engineered safety methods including hazard suppression
- Development of prudent life-cycle safety testing and evaluation methodologies

- Development of new or enhancement of existing codes, standards and regulations (CSR), including the necessary safety documenting to accommodate existing knowledge, and translation of the growing body of experience and results of other ESS Safety initiative activities into future CSR
- Establishment of ESS requirements for ensuring safety of first and second responders (including post event re-commissioning or decommissioning), ranging from ESS design parameters (consistent with prudent risk management) to on-site signage, training, and information sharing
- Creation of a comprehensive information resource to serve as a clearinghouse of related reports and information, share progress in activities listed above, and document relevant safety incidences and off-normal events that are reported for deployed systems

Reaching the desired end state will require collaboration and contribution from many stakeholders. DOE will serve as a facilitator and convener of stakeholders to coordinate and support advancement of energy storage safety for grid applications. DOE will broadly engage stakeholders and support enhanced leadership by industry or stakeholder associations, as appropriate. DOE will organize an external stakeholder group whose mission will be to advise DOE on efforts to ensure ESS are developed, used, and decommissioned in a safe manner and that communities embrace ESS as safe technologies.

DOE programmatic efforts will focus on four elements:

- ESS safety technology
- Risk assessment and management
- Incident response
- Codes, standards and regulations

The goals, scope, near-term actions, and long-term agenda are described for each of these elements below. Near-term activities that will receive *high priority* are identified with bold italic text. While DOE may serve as a convener and principal performer for some activities that are beyond the current reach of industry and regulators, it is anticipated that many organizations, not mentioned here, will serve in critical roles, provide thought leadership and have extensive involvement.

8.1 ESS Safety Technology

Goal: The scientific and technical basis for ensuring ESS safety is well established and ESS stakeholders are incorporating new technologies that further enhance ESS safety or enable achievement of safe ESS at lower cost.

Scope: Ensuring, enhancing and validating ESS safety is underpinned by scientific and technical understanding of physical and chemical behavior of energy storage systems and associated life-cycle factors affecting their behavior (such as construction, transportation, installation, operation, decommissioning and disposal). This understanding requires both effective testing methods and methodologies (and their implementation), as well as validated models of ESS capable of assessing hazards under both normal and abnormal circumstances. Safety testing methods, informed by both experience and models, will be assembled to address inherent hazards as well as engineered safety systems through all system life stages. Models will be developed to characterize both inherent hazard attributes of materials and designs, as well as evaluate various engineered safety measures. Efforts will also be undertaken to identify and assess the relevant hazard attributes of alternative materials and designs that have the potential to reduce risks or achieve equally satisfactory risk levels at reduced cost.

Near-term Actions: ***Stakeholders will be surveyed to identify the ESS hazards most in need of attention based on the perceived risk levels, deployment activity, CSR status, and incident experience, for major classes of ESS.*** Plans for hazard characterization and mitigation testing and evaluation will be assembled for each major class of ESS. Preliminary models, suitable for hazard analysis for these ESS classes, will be assembled in conjunction with key stakeholders. Preliminary safety testing methodologies for ESS (and components thereof, as appropriate) will be assembled with key stakeholders. Of particular near-term interest is addressing scientific and technological gaps in existing CSR that impede ESS deployment.

Long-term Agenda: Consistent with the risk assessment and management framework, stakeholders will periodically reevaluate the hazards to ensure that safety information is consistent with evolving technologies, at both the component and system level, and the ever-expanding application spaces. Models and testing protocols for characterization and evaluation of ESS hazards will be refined and validated. Efforts will progressively shift from characterization of potential hazards to the development of alternative materials, designs and engineered safety systems that enable thorough safety validation that is economically viable.

8.2 Risk Assessment and Management

Goal: The framework and methodologies for assessing and managing deployment risk for ESS are accepted and adopted by industrial and regulatory stakeholders.

Scope: A general framework for risk assessment will be developed based on existing approaches employed for other established or emerging power system technologies but adapted for ESS use. This risk assessment framework will enable differentiation of risks for specific ESS classes of technologies consistent with existing risk management approaches. The framework will provide a means to harmonize science-based hazard analyses, as well as codes and standards and incidence response considerations. The evolving framework will permit early consideration of the wide range of factors affecting life-cycle safety. Based on this framework, specific tools will be developed to trade off and manage risk elements during design, transport, life-cycle operation, off-normal events and incidents, and retirement.

Near-Term Actions: ***A survey of industry and the responder community will be conducted regarding existing risk management frameworks will be conducted to identify candidate model frameworks as well as elements that might prudently be incorporated from other technologies. A straw-man framework will be prepared and reviewed by industry and regulatory representatives.*** A straw example of an assessment for a specific ESS technology will be developed to help explore the translation of the framework to practice, and the interactions with various other safety related interests such as operations, CSR, permitting, insurance, incident response, etc. Again, this example will be used to revise the framework and address specific technologies.

Long-term Agenda: The risk framework will continue to be refined and the implementation methodology will be applied to specific ESS technologies. Greater effort will be undertaken to harmonize the risk framework across other program elements and to identify and more thoroughly characterize the ESS risk framework and assessment methodologies.

Tools to better characterize the risks and their evolution during specific periods of ESS deployment (e.g. manufacture, acceptance testing, inventory, transportation, commissioning, operation, off-normal events, incident response, decommissioning, recycle or disposal) will be developed and disseminated. These tools are intended to enable tradeoff analysis to ensure safe systems that accommodate other societal goals (e.g. economic, environmentally desirable, efficient, robust, reliable, etc.).

8.3 Incident Response

Goal: First and second responders (including on-site staff) are well informed and equipped to address hazardous incidents regarding ESS, at all life stages, with no health impacts and minimal property loss.

Scope: Incident response focuses on preparation and training for first and second responders who may be called upon to enter hazardous conditions to limit destructive consequences of an ESS incident. Approaches for managing incident progression and consequences for all ESS will be identified and disseminated, thereby minimizing potential safety consequences (during and after the incident), and limiting property loss. Model ESS hazard documentation, incident action plans and incident response guidelines will be prepared and disseminated. Recommended notification, postings, system design, hazard management, and incident response practices will be provided. CSR relevant to ESS safety and incident response will be updated to address ESS. Training programs will be developed and used to prepare incident responders to obtain an awareness level to best deal with potentially hazardous ESS events, for all types of ESS and for all ESS life stages. ESS incident response issues amenable for addressing by improved technology will be identified and communicated to those developing ESS safety technology. Furthermore, testing and evaluation of incident response technology will be conducted. ESS incidents involving potentially hazardous circumstances will be catalogued and used to improve incident response methods, equipment, CSR, and after-incident evaluation, re-commissioning or decommissioning.

Near-term Actions: ***Documentation of reported ESS hazardous incidents will be assembled for use by all stakeholders. Guidelines for ESS hazard identification and documentation, postings and signage, and incident response preparations will be established.*** General guidelines on system design and installation, including recommendations for site safety systems (e.g. fire suppression) will be developed. ***A review of ESS CSR relevant to incident response requirements will be undertaken.***

Long-term Agenda: An ESS education and training curriculum will be developed and used for educating incident responders. Testing and evaluation of incident response technologies for ESS will be undertaken consistent with priorities established with incident response stakeholders. CSR development will be monitored and updates will be identified to enable improved incident response. Guidelines for ESS design and installation will be updated as new technologies become available, additional information on ESS incidents is documented, and new engineered safety systems are implemented.

8.4 Codes, Standards and Regulations

Goal: Codes, standards and regulations enable the deployment of safe ESS in a comprehensive, non-discriminatory, and institutionally efficient manner.

Scope: The tapestry of codes, standards and regulations that are relevant to safe development, deployment, and disposal of ESS, combined with the array of ESS technologies, and suite or potential applications create a complex environment for assurance of ESS safety. Therefore, the following actions will be undertaken: characterizing this environment; identifying and addressing critical near-term issues affecting CSR treatment of storage; expanding the breadth and depth of CSR treatment of ESS; and incorporating advances born of ongoing research, development, demonstration, and deployment in ESS-relevant CSR. Coordinated engagement of ESS stakeholders to prepare and prosecute revision and update of CSR through official CSR organizations will be performed, initially to provide timely contributions to ongoing CSR revision processes. Comprehensive mapping and coordination of safety-related efforts undertaken by DOE-coordinated activities, as well as those of other stakeholders such as Electric Power Research Institute (EPRI), Energy Storage Association (ESA), National Alliance for Advanced Technology Batteries (NAATBatt), National Electrical Manufacturers Association (NEMA), National Fire Protection Association (NFPA), etc., to ensure timely, comprehensive, technology neutral support of standards and code-making bodies will be undertaken to accomplish the goal. Guidance will be provided to ESS suppliers, project developers, utilities, customers, regulators and the CSR community regarding ESS-relevant CSR, not only to minimize potential safety incidents but also to improve CSR implementation efficiency. ESS-relevant CSR will be catalogued and tracked to enable the ESS community to remain abreast of the status of CSR requirements.

Near-Term Actions: ***A description of how codes and standards relevant to ESS are structured and used will be prepared as a primer on ESS CSR. A catalogue of existing relevant CSR that are relevant to ESS will be assembled. Engagement of time-critical CSR revision processes that are important for ESS will be undertaken (e.g. the National Electrical Code) in collaboration with ESS industry stakeholders.*** A thorough review of existing CSR regarding gaps related to ESS will be conducted; the gaps will be prioritized and approaches for their resolution will be determined; efforts will be undertaken to resolve the gaps based on their priority, focusing on those that are potential "showstoppers." Authorities having jurisdiction (AHJ) will be engaged, in regions where ESS is being actively deployed, to provide information and assistance related to resolving CSR uncertainties, and to gain insights on CSR challenges for ESS.

Long-Term Agenda: Gaps in CSR that require additional technical research, development, and demonstration will be identified and specific technical RD&D will be defined. Organizations responsible for promulgation of CSR will be engaged in an on-going, active basis to facilitate the progress of CSR revisions that are necessary to enable or facilitate deployment of ESS. CSR-relevant information and experience will be assembled and disseminated in a manner that enables frequent update and feedback. Where possible, model-CSR will be assembled to guide organizations in developing, modifying, or applying ESS-relevant CSR. An initiative will be undertaken to provide up-to-date training and education on ESS-relevant CSR. Periodic review of existing and proposed CSR relevant to ESS will be performed. Periodic surveys of CSR experiences and "events" will be performed to enable tuning of CSR support activities, and ensure up-to-date information for AHJ officials.

Appendix

A. List of DOE OE Energy Storage Safety Workshop Participants and Affiliations

Last Name	First Name	Affiliation
Gyuk	Imre	DOE OE
Acker	William P.	New York Battery and Energy Storage Technology Consortium, Inc.
Agarwal	Arun	DNV GL
Aguirre	Victor	Tucson Electric Power
Akhil	Abbas	Sandia National Laboratories, NM
Allendorf	Sarah	Sandia National Laboratories, CA
Andrews	George	Oak Ridge National Laboratory
Atcitty	Stanley	Sandia National Laboratories, NM
Baumgart	Gary	Curtiss Wright
Bear	Neal	FM Global
Becker	Martin	Princeton Power
Bocra	Gina	NYC Building Commission
Borneo	Dan	Sandia National Laboratories, NM
Bowles	Ryan	Duke Energy
Chalamala	Babu	SunEdison
Chaos	Marcos	FM Global
Chatwin	Troy	General Electric Company
Conover	Dave	Pacific Northwest National Laboratory
Cook	Kevin	McKean Defense
Danley	Doug	Contractor to NRECA Cooperative Research Network
Darrow	Chris	Imergy Power Systems
Dedrick	Daniel	Sandia National Laboratories, CA
Doughty	Daniel	Battery Safety Consulting, Inc.
Drew	Tim	California Public Utilities Commission
Duffy	Chad	National Fire Protection Association

Ferreira	Summer	Sandia National Laboratories, NM
Fioravanti	Richard	DNV GL
Florence	Laurie B.	UL
Franks	Ryan	National Electrical Manufacturers Association
Ganguli	Sham	FM Global
Hanley	Charles	Sandia National Laboratories, NM
Hearne	Sean	Sandia National Laboratories, NM
Hires	Jeff	GS Battery
Hockney	Richard	Beacon Power
Horne	Craig	EnerVault
Huque	Aminul	Electric Power Research Institute
Kamath	Haresh	Electric Power Research Institute
Kannberg	Landis	Pacific Northwest National Laboratory
Lazarewicz	Matt	Helix Power
Lee	Sang Bok	University of Maryland
Li	Liyu	UniEnergy Technologies
Lin	Roger	A123 Systems, LLC
Marshall	Andrew	Primus Power
McNutt	Ty	APEI
Meola	Carmine	ACI Technologies, Inc.
Noland	Jamie	Aquion Energy
Orendorff	Christopher	Sandia National Laboratories, NM
Orkney	Justin	Tucson Electric Power
Orrell	Andrew	Sandia National Laboratories, NM
Paiss	Matt	San Jose Fire Department
Pinksy	Naum	Southern California Edison
Porter	David	S&C Electric Company
Rima	Chris	Tucson Electric Power
Rinehart	Larry	Rinehart Motion
Rose	David	Sandia National Laboratories, NM

Scott	Paul	TransPower
Smith	Ryan	EPC Power
Smith	Matthew	NextEra Energy Resources
Sprenkle	Vince	Pacific Northwest National Laboratory
Stosser	Michael	Sutherland Asbill & Brennan LLP
Sullivan	John	Sandia National Laboratories, CA
Torre	William	University of California, San Diego
Weed	Russ	UniEnergy Technologies
Wessels	Colin	Alveo Energy
Wiles	John	New Mexico State University
Willard	Steve	PNM Resources
Willette	Kenneth	National Fire Protection Association
Wills	Robert	Intergrid, LLC/ Aquion Energy
Wunsch	Tom	Sandia National Laboratories, NM

B. Abridged List of Relevant Codes, Standards and Regulations

Several Occupational Safety and Health Administration (OSHA) standards explicitly require employers to have emergency action plans for their workplaces:

General Industry (29 CFR 1910) Requirements for Emergency Response and Preparedness[75]

General Requirements for Workplaces:

- 29 CFR 1910.36 Design and construction requirements for exit routes
- 29 CFR 1910.37 Maintenance, safeguards, and operational features for exit routes
- 29 CFR 1910.151 Medical services and first aid
- 29 CFR 1910.157 Portable fire extinguishers
- 29 CFR 1910.165 Employee alarm systems

Additional Requirements for Workplaces Referenced in Other Requirements:

- 29 CFR 1910.38 Emergency action plans
- 29 CFR 1910.39 Fire prevention plans
- 29 CFR 1910.269 Electric power generation, transmission and distribution
- UL 1642: Lithium Batteries
- UL 1973: (Proposed) Batteries for Use in Light Electric Rail (LER) Applications and Stationary Applications
- UL 2054: Household and Commercial Batteries
- UL Subject 2271: Batteries For Use in Light Electric Vehicle Applications
- UL 2575: Lithium-Ion Battery Systems for Use in Electric Power Tool and Motor Operated, Heating and Lighting Appliances
- UL Subject 2580: Batteries for Use in Electric Vehicles

The National Fire Protection Association has several standards on ESS and Fire Protection recommended practices for electrical generating plants:

- NFPA 110 – Standard for Emergency and Standby Power Systems

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[75] https://www.osha.gov/Publications/osha3122.html

- NFPA 111 - Standard on Stored Electrical Energy Emergency and Standby Power Systems
- NFPA 850 - Recommended Practice for Fire Protection for Electric Generating Plants and High Voltage Direct Current Converter Stations
- NFPA 851 - Recommended Practice for Fire Protection for Hydroelectric Generating Plants
- NFPA 853 - Standard for the Installation of Stationary Fuel Cell Power Systems

C. References for Validation Techniques

1. Fire Retardants

Name of Fire Retardant	Reference
Phosphate/Phosphonate	
Triphenylphosphate (TPP)	[a15]
Vinyl ethylene carbonate (VEC) + biphenyl (BP) + TPP	[a16]
Dimethyl methylphosphonate (DMMP)	[a17] [a18]
Polyphosphonate	[a19]
Triphenyl phosphate (TPP), tris(trifluoroethyl)phosphate (TFP)	[a20]
Phosphorus-containing esters	[a21]
Methoxyethoxyethoxyphosphazenes	[a22]
Bis(N,N-diethyl)methoxyethoxymethylphosphonamidate	[a23]
Triphenyl Phosphate (TPP) and Trinutyl Phosphate (TBP)	[a24]
Trimethyl Phosphate (TMP) and Triethyl Phosphate (TEP)	[a25]
Ethylene Ethyl Phosphate(EEP) + TMP	[a26]
Diphenyloctyl phosphate(DPLP)	[a27]
Cyclic phosphate	[a28]
Fluorinated Phosphate/Ethers	
Tris(Trifluoroethyl)Phosphate (TFP), Bis(trifluoroethyl)Methyl Phosphate (BMP) and Trifluoroethyl Phosphate (TDP)	[a29, 30]
Flame retardant additives	
Methyl Nonafluorobutyl Ether (EFE)	[a31, 32]
Perfluoro-Ether	[a33]
Hydrofluoro Ether (HFE)	[a34, 35]
Phosphites	
Tris(2,2,2-Trifluoroethyl) Phosphite (TTFP)	[a36, 37]

Triethyl and Tributyl Phosphite	[a38]
Trimethyl phosphite (TMP)	[a39]
Ionic Liquids	
N-butyl-N-methylpyrrolidinium bis(fluorosulfonyl)imide (PYR14FSI)	[a40, 41]
N-butyl-N-methylpyrrolidinium bis(trifluoromethansulfonyl)imide, PYR14TFSI	[a42]
1-ethyl-3- Methylimidazolium tetrafluoroborate (EMIBF4)	[a43]
Tri-(4-methoxythphenyl) phosphate (TMTP)	[a44]
Miscellaneous compounds	
Hexamethylphosphoramide (HMPA)	[a45]
Dimethyl Methylphosphonate (DMMP)	[a46]
Phosphazene	
Phoslyte	[a14]
Ethyleneoxy Phosphazenes	[a22, 47]
Phosphazene-based flame retardants	[a48]
Hexamethoxycyclotriphosphazene	[a49, 50]

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2. *Flash Point for some Common Organic Materials*

Flash Point* for some of the common organic materials

Chemical	Flash Point (ºC)
Acetone	-17
Ethanol	17
Gasoline	-42
DEC	33
DMC	18
EMC	23
EC	145
PC	132
HFEs (TMMP, TPTP)	No flash point
IL (1-ethyl-3-metgyl imadazolium TFSI)	283
Canola oil	327

Acronym List

A

AHJ	Authorities Having Jurisdiction
ANSI	American National Standards Institute
ASTM	American Society for Testing and Materials

B

BEWAG	West Berlin Electric Utility Company
BMP	Bis(trifluoroethyl)Methyl Phosphate
BP	Biphenyl

C

C	Centigrade
CAES	Compressed Air Energy Storage
Cl	Chloride
CID	Current interrupt devices
CO_2	Carbon Dioxide
CRA	Community Risk Assessment
CSR	Codes, Standards, and Regulations

D

DC	Direct current
DEC	Diethyl carbonate
DMC	Dimethyl carbonate
DMMP	Dimethyl methylphosphonate
DOE	Department of Energy
DSC	Differential Scanning Calorimetry

E

EC	Nusan 30 E.C.
EDV	Electric-drive vehicle
EFE	Methyl Nonafluorobutyl Ether
EMC	Ethyl methyl carbonate
EMIBF4	Methylimidazolium tetrafluoroborate
EPCRA	Emergency Response and Community Right to Know Act
EPRI	Electric Power Research Institute
ESA	Energy Storage Association
ESS	Energy Storage System
EV	Electric Vehicle

F

FEMA	Federal Emergency Management Agency
FERC	Federal Energy Regulatory Commission
FMEA	Failure Mode and Effects Analysis
F_P	Flash Point
FPRF	Fire Protection Research Foundation
FR	Fire Retardants

G

GW	Gigawatt

H

HFE	Hydrofluoroethers
HMPA	Hexamethylphosphoramide

I

ICE	Internal combustion engine
IEC	International Electrotechnical Commission

IIPP	Illness and Injury Prevention Plan
IL	1-ethyl-3-metgyl imadazolium TFSI
IR	Infrared
ISO	Independent system operator

K

kW/kWh	Kilowatt/Kilowatt hour

L

LER	Light Electric Rail
Li	Lithium
LOI	Limited oxygen index

M

MW/MWh	Megawatt/megawatt hour

N

Na	Sodium
NAATBatt	National Alliance for Advanced Technology Batteries
NEMA	National Electrical Manufacturers Association
NEPA	National Environmental Policy Act
NFPA	National Fire Protection Association
Ni	Nickel

O

OE	Office of Electricity Delivery and Energy Reliability
OSHA	Occupational Safety and Health Administration

P

Pb	Lead

PC	Propylene carbonate
PPE	Personal protective equipment
PREPA	Puerto Rico Electric Power Authority
PTC	Positive temperature coefficient
PYR14FSI	N-butyl-N-methylpyrrolidinium bis(fluorosulfonyl)imide

R

R&D	Research and Development
RTO	Regional transmission organization

S

s	Seconds
SDO	Standards development organization
SDS	Safety data sheets
SET	Self-extinguishing time
Si	Silicon
SMES	Superconducting Magnetic Energy Storage

T

TDP	Trifluoroethyl phosphate
TFSI	Bis(trifluoromethanesulfonyl)imide, trifluoromethanesulfonimide
TMMP	2-trifluoromethyl-3methoxyperfluoropentane
TMTP	Tri-(4-methoxythphenyl) phosphate
TPTP	Trifluoropentane
TTFP	Tris(2,2,2-Trifluoroethyl) Phosphite

U

UFC	Uniform Fire Code
UL	Underwriters Laboratories
UPS	Uninterruptible power supplies
USABC	United States Advanced Battery Consortium

V

Vdc	Voltage direct current
VEC	Vinyl ethylene carbonate
VRB	Vanadium Redox Flow

CAL FIRE–Office of the State Fire Marshal
November 2010

FIRE OPERATIONS FOR *Photovoltaic Emergencies*

FIRE OPERATIONS FOR *Photovoltaic Emergencies*

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Contents

MISSION STATEMENT

The mission of State Fire Training is to enable the California fire service to safely protect life and property through education, training, and certification.

FIRE SERVICE TRAINING AND EDUCATION PROGRAM

The Fire Service Training and Education Program (FSTEP), was established to provide specific training needs of local fire agencies in California. State Fire Training coordinates the delivery of this training through the use of approved curricula and registered instructors.

The FSTEP series is designed to provide both the volunteer and career fire fighter with hands-on training in specialized areas such as fire fighting, extrication, rescue, and pump operations. All courses are delivered through registered instructors and can be tailored by the instructor to meet your department's specific need. Upon successful completion of an approved FSTEP course, participants will receive an Office of the State Fire Marshal course completion certificate.

ACKNOWLEDGMENTS

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Arnold Schwarzenegger, Governor

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Michael Richwine, Chief, State Fire Training

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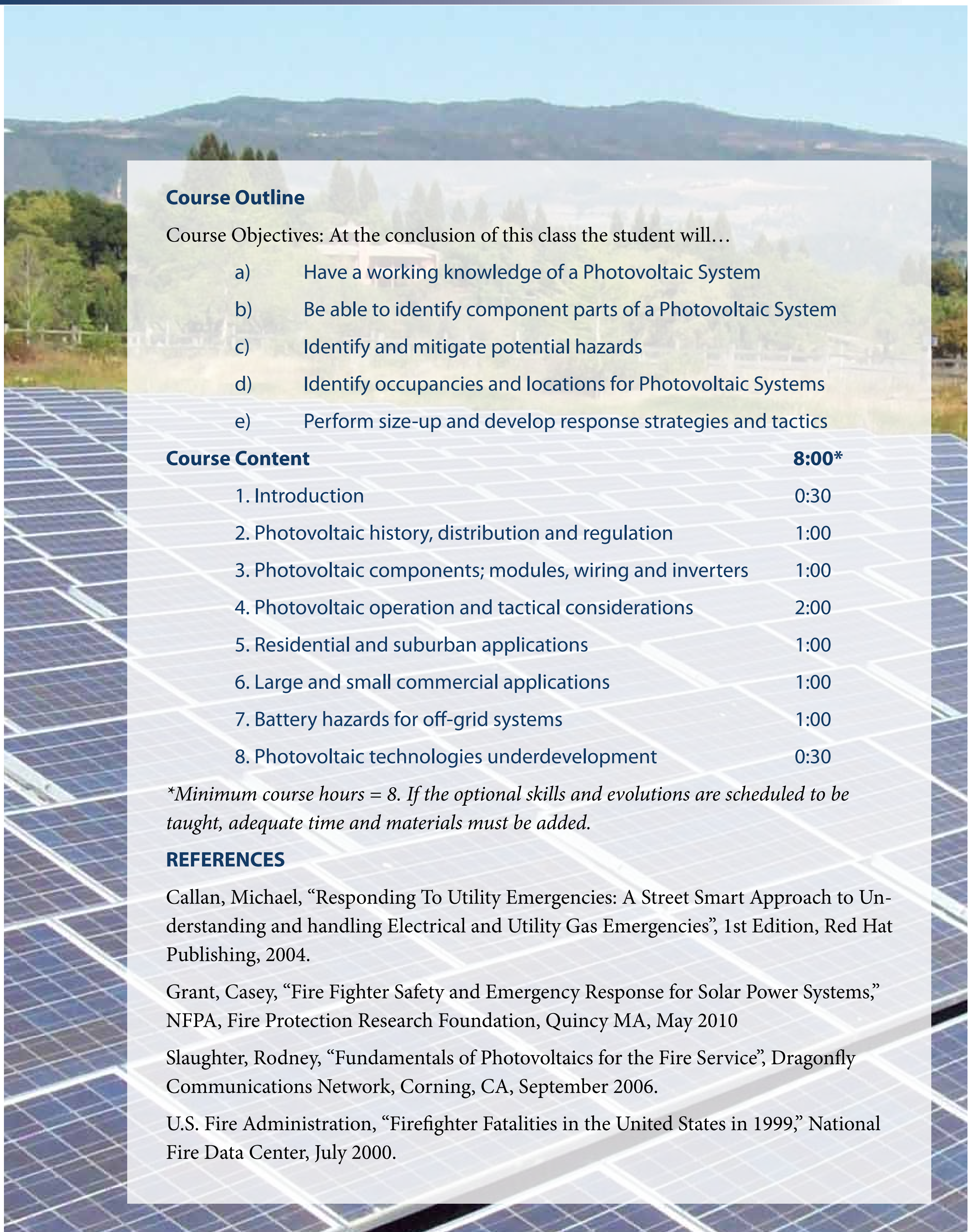
Mike French, B. P. Solar



Course Outline

Course Objectives: At the conclusion of this class the student will…

a) Have a working knowledge of a Photovoltaic System

b) Be able to identify component parts of a Photovoltaic System

c) Identify and mitigate potential hazards

d) Identify occupancies and locations for Photovoltaic Systems

e) Perform size-up and develop response strategies and tactics

Course Content	**8:00***
1. Introduction	0:30
2. Photovoltaic history, distribution and regulation	1:00
3. Photovoltaic components; modules, wiring and inverters	1:00
4. Photovoltaic operation and tactical considerations	2:00
5. Residential and suburban applications	1:00
6. Large and small commercial applications	1:00
7. Battery hazards for off-grid systems	1:00
8. Photovoltaic technologies underdevelopment	0:30

**Minimum course hours = 8. If the optional skills and evolutions are scheduled to be taught, adequate time and materials must be added.*

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Terminal Objective

At the conclusion of this module students will be able to recognize types of photovoltaic systems and components

Enabling Objective

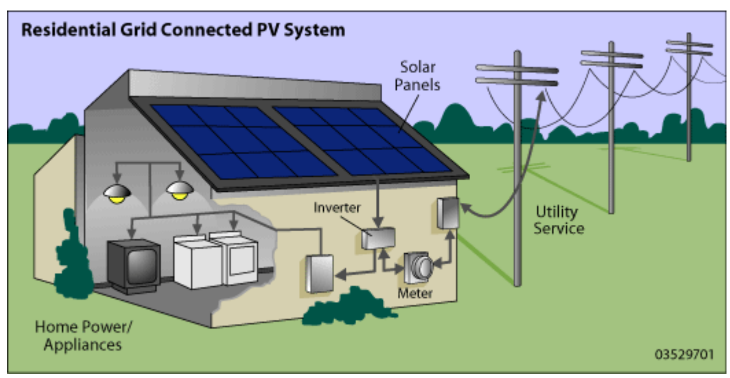
The student will be able to:

- Describe a photovoltaic system
- Identify system components

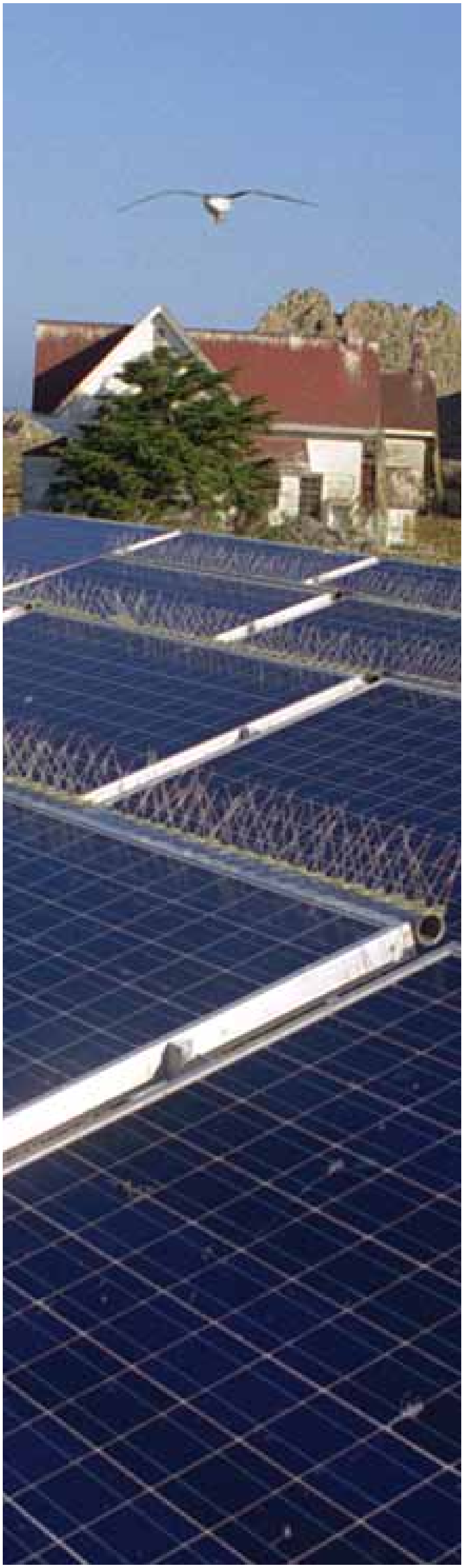
1.1 INTRODUCTION

With a variety of alternative electrical generation systems available, none is becoming more prevalent than those which convert solar energy to electricity. These systems are known as photovoltaic systems, or simply PV. A photovoltaic system consists of photovoltaic solar panels and other electrical components used to capture solar energy and convert it to electrical power. Many systems are roof mounted and may present hazards to firefighting operations. Firefighters can be sure that at some point in the future they will encounter an incident involving a building with a solar electric generating system.

PV systems are an economical and environmentally clean way to generate electricity and are here to stay. Your fundamental understanding of PV systems will increase your confidence when fighting fires involving PV equipment and when fighting fires in structures equipped with PV systems. The PV industry, utility companies, manufacturers, suppliers, regulators, designers and installers are working with fire service to ensure that firefighters will be able to operate safely around PV systems.



The days of firefighters rushing in to a structure without first making an assessment and size-up of the emergency have passed. In addition to a several other hazards found in fighting fire in modern buildings, Fire fighters must also be aware of PV systems and the associated hazards. The potential hazards, which will be discussed in this curriculum include, electrical shock, trip/slip/fall, increased roof loads, hazardous materials, and battery storage hazards. This training curriculum will review these dangers and hazards as well as make recommendations on how you can protect your fire crew members and yourself.



The information contained in this curriculum is specific to California. If used in other states or countries, some of the discussion should be updated to reflect local energy policies and regulations.

1.2 WHAT ARE PHOTOVOLTAICS?

"Photovoltaics" refers to the process of converting energy in the form of light from the sun to usable electrical current. A PV system refers to a system of components that, together, will generate electricity for use on site and may allow excess electricity to flow to the utility grid.

Since the 1980s, solar electricity has been used in many common household devices. You probably remember the early solar-powered calculators that didn't need a battery and small solar charging systems for recreational vehicles and boats. But this was just the beginning. The solar electric industry is now actively selling and installing PV systems throughout California. At the end of 2009, there were approximately 50,000 individual solar projects scattered throughout California on residential and commercial properties. Residential systems can create enough electricity to meet a home's entire annual energy needs. There are also thousands of solar thermal systems in California, which are used to provide hot water and home heating. This curriculum does not cover solar thermal water heating systems.

Everyday solar electricity can be found in bookbags, solar calculators, and landscape lighting.

There are a variety of PV types and installations, but generally a PV system includes:

- **Modules:** Modules, also called panels, are made up of many round or square cells, which create electricity when exposed to sunlight. The cells are connected together using materials that allow the electrons to flow into a system of electrical connections. A group of modules is called a 'string' and a group of strings is called an 'array.'
- **Wiring harness:** Wiring harnesses are used to wire modules together in series. A group of strings are connected together at a junction called a combiner box. From the junction box(s) conductors carry the electricity to the inverter.

- **Inverter:** PV panels produce direct current which generally needs to be converted to alternating current. This is done by an inverter. The inverter is connected to the on-site utility service panel, so that electricity from the solar array can provide electricity to the site.
- **Batteries:** Batteries are used in "banks" store electricity.
- **Disconnect Switches:** A PV system may have one or more disconnect switches between the arrays and the electrical service panel.

In other than off-grid systems, most PV systems installed today do not use batteries. Instead, the systems produce electricity for use on site or for transmission to the local utility. When more electricity is produced from the solar panels than is needed on site, the extra electricity is allowed to flow into the utility system. The surplus current runs through a meter that measures how much of electricity flows into the utility grid. The elimination of batteries has reduced the cost and increased the practicality of PV systems thereby allowing PV to be more available to consumers.

1.3 STATE SAFETY REGULATIONS

Regulations in the National Electrical Code addressing solar electrical safety have been in place since the 1980s. As PV technology has evolved, so have the applicable codes and ordinances. Like all evolving technologies, practical experience plays an important role in the development of new regulations.

In 2007, the California Office of the State Fire Marshal (CAL FIRE) established a task force that included representatives from the fire service, building officials, other state agencies, and the PV industry in order to develop a guideline for the installation of PV systems. The Solar Photovoltaic Installation Guideline was developed to provide local jurisdictions and the solar industry with information for the layout, design, marking, and installation of solar photovoltaic systems. The Guideline can be located on-line at *http://osfm.fire.ca.gov/training/photovoltaics.php* and is intended to mitigate the fire and life safety issues. In addition, the Guideline provides labeling recommendations to help the fire service identify the components of the PV system at the scene of a fire. In May 2010, the International Code Council adopted a version of the California Guideline into the 2012 International Fire Code.

1.4 NUMBER OF PV SYSTEMS IN CALIFORNIA

Changes in PV technology, such as efficiency and availability have lowered the price of PV systems. As a result, the number of solar installations has increased dramatically. Figure 1 shows a chart of the number of solar projects installed between 2001 and 2009 in the regions served by Pacific Gas & Electric (PG&E), Southern California Edison (SCE), and San Diego Gas & Electric (SDG&E). Table 1 shows the actual numbers in these same utility areas.

Figure 1: Number of solar projects in California, 2001-2009

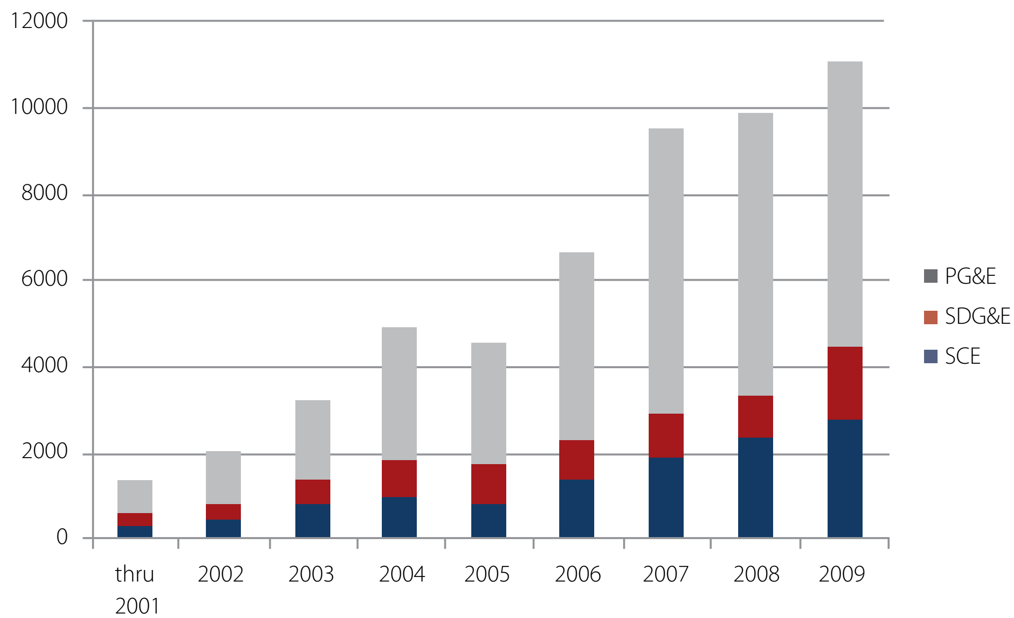


Table 1: Number of PV Projects by Utility Area

Utility Area	thru 2001	2002	2003	2004	2005	2006	2007	2008	2009
SCE	*294*	*446*	*801*	*939*	*807*	*1344*	*1873*	*2352*	*2769*
SDG&E	*306*	*350*	*537*	*861*	*934*	*961*	*1028*	*951*	*1658*
PG&E	*745*	*1243*	*1856*	*3104*	*2824*	*4348*	*6578*	*6547*	*6607*
Total	*1345*	*2039*	*3194*	*4904*	*4565*	*6653*	*9479*	*9850*	*11034*

Even though incentives are available statewide, most PV projects are installed in areas where electricity use and rates are high. Typically, these are areas in which the use of air conditioning is highest. Utilities in California use a tiered billing system; the rate paid for electricity by the consumer is higher based upon the quantity of electricity used. However, some customers choose to install PV systems simply out of concern for the environment or climate change.

Table 2 shows the Cities and Counties with the most Residential PV systems installed between 2007 and February 2009.

Table 2: Residential PV Systems in Cities and Counties, January 2007- February 2009[1]

Counties	Cities
San Diego 3,098 (12.1%)	San Diego: 1,095 (4.3%)
Santa Clara: 2,291 (9.0%)	San Francisco: 1,012 (4.0%)
Los Angeles: 2,191 (8.6%)	San Jose: 851 (3.3%)
Alameda: 1,465 (5.7%)	Fresno: 540 (2.1%)
Contra Costa: 1,175 (4.6%)	Clovis: 389 (1.5%)
Sonoma: 1119 (4.4%)	Santa Rosa: 368 (1.4%)
Riverside: 1101 (4.3%)	Oakland: 301 (1.2%)
Fresno: 1089 (4.3%)	Berkeley: 294 (1.2%)
San Francisco: 1,013 (4.0%)	Santa Cruz: 291 (1.1%)
Other/Unspecified: 9,609 (37.6%)	Other/Unspecified: 19,997 (78.2%)

To obtain more recent statistics on solar projects constructed in California Cities and Counties, visit *www.californiasolarstatistics.ca.gov.*

Some communities provide on line solar maps, showing where solar projects have been installed in their communities. Table 3 shows a list of a few of the solar maps available in California.

[1] *Source: www.californiasolarstatistics.ca.gov*

Table 3: Solar Map Websites

City	Web site
San Francisco	*http://sf.solarmap.org/*
Los Angeles	*http://solarmap.lacounty.gov/*
San Diego	*http://sd.solarmap.org/solar/index.php*
Berkeley	*http://berkeley.solarmap.org/solarmap_v4.html*
Sacramento	*http://smud.solarmap.org/map.html*
San Jose	*http://www.sanjoseca.gov/esd/energy/svenergymap.asp*

1.5 INCIDENT SUMMARY

As the number of PV systems has increased, fire service experience with theses systems has also grown. In addition, the fire service has experienced several fires involving buildings equipped with PV and fires involving the PV components. These experiences have not resulted in death or serious injury to firefighters but they have highlighted the need for the solar industry to work with the fire service.

Table 3 shows a brief summary of incidents that have been reported. Lessons learned from these incidents will be used in case studies and examples in this training material.

A content fire in the garage of this residence destroyed the PV inverter box.

Table 4: Incident Summary

Date	Location	Summary
June 1996	Grassy Area	Small grass fire originating from PV modules.
2003	San Bernardino (Devore, CA)	Residential wildfire in the region. Building and PV system survived (all other buildings destroyed)
2004	Strip Mall	Overheated junction box with smoke and no fire.
Feb 2008	Long Beach, CA	Convention center fire on two modules. The modules involved were field repaired by the manufacturer representative. Damage limited to the modules.
June 2008	Sedona AZ	Residential content fire. PV system was destroyed. Firefighter received an electric shock (non life threatening) that was first attributed to the PV system but later attributed to the utility power supply.
May 2008	San Francisco, CA	University of San Francisco fire started at the array and extinguished by maintenance personnel.
Jan 2009	Torrance, CA	Residential fire started at PV modules 2 weeks after the system was installed. The modules were 'do-it-yourself' of questionable installation quality.

June 2009	Concord, CA	Concord CA- Residential Garage fire. PV system not involved and did not burn (although inverter was destroyed because of the extent of the fire. The PV system did not cause the fire.
Mar 2009	Simi Valley, CA	Residential fire started in a shingle module of an integrated roof PV system.
Apr 2009	Bakersfield, CA	Big Box retail store fire may have started in the PV conduit or the array.
Summer 2009	San Francisco, CA	Convention Center incident. PV Modules observed arcing. No fire occurred. Modules replaced.
Summer 2009	Davis, CA	Grass fire at PV USA a former PV research center.
June 2009	Bursdadt, Germany	Large warehouse. Fire occurred at the PV modules (200 square feet of a 5 MW system) within the array.
Jan 2010	Minnesota	A chimney fire that was originally attributed to nearby roof-mounted air heating panels but later corrected.
Mar 2010	Victorville, CA	Concentrating modules burned while stored on site before installation took place. Fire likely caused by a cigarette or other burning material that came in contact with the boxes where the modules were stored.
Apr 2010	Maryland	Residential fire—Older PV system. Fire started at modules. Reports are debris beneath modules may have been involved in the cause of the fire.
Apr 2010	San Diego, CA	Residential fire on an 8 year old, self-installed PV system, started at the inverter. PV modules not involved. The lack of an external DC disconnect, prevented resident and emergency responders from turning off power from the modules.
May 2010	Fresno	A Fresno College campus a fire occurred in the combiner box of a PV system, mounted on a parking structure.

This brief summary of PV incidents chronicles a range of issues that are associated with PV. But this review reveals that some of these problems did not start with the PV system, but from inexperienced installations, installations using damaged panels, and incidents that occurred before the PV system was actually installed. Importantly, some of these incidents started as a result of overheated arrays and junction boxes. While some PV systems were involved with a structural fire, they were not the origin of the fire. In all cases, developing a fundamental understanding of PV systems will help you stay safe when operating around the system and help you mitigate potential emergencies.

Each cell of a PV module is wired together to the junction box on the back side of the module. The picture, lower left, shows the damage to the junction box after it becomes overheated.

Terminal Objective

At the conclusion of this module students will have knowledge of the basic parts of a PV system.

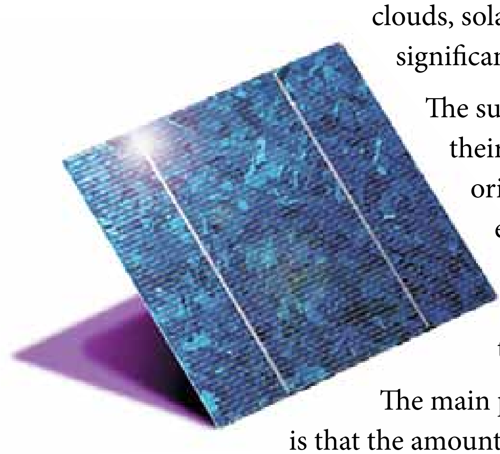
Enabling Objective

The student will be able to:

- Describe the basic parts of a PV panel
- Identify system components
- Understand basic design considerations

2.1 INTRODUCTION

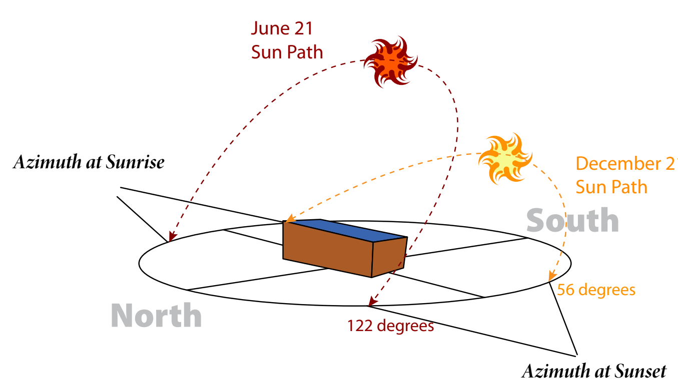
Photovoltaics begin at the source—the Sun! Every day enough solar energy falls on the earth to supply all the world's energy needs for four to five years. The Sun's full intensity and brightness, often called "peak sun", is 1,000 watts per square meter (referred to as irradiance). This intensity can be diminished by the micro climate and site specific conditions, such as weather and shade. But even on overcast days caused by smog or clouds, solar electricity can still be generated by the solar panels, although at significantly reduced efficiency.

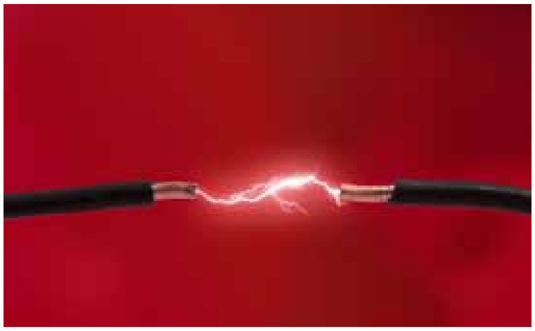


The sun produces the most energy between 9 am and 3 pm. To maximize their efficiency, most PV systems in the Northern Hemisphere are orientated toward the south. Understanding how solar cells generate electricity is one thing. Understanding what to do with all that electricity is another. In many cases, a PV system will generate more electricity during the sunniest part of the day than can be used at the time.

The main point that a firefighter needs to have about PV electrical generation is that the amount of current generated depends on how intense the sunlight is. If the sunlight doubles in intensity, the current generated by the array will also double.

The current is not unlimited as with energy supplied by a utility service. For a utility service, a short circuit can generate 10,000 amps at a residence to 100,000 amps at a large commercial facility. These high short-circuit currents at utility services are a severe hazard to the firefighter. PV systems, on the other hand, are limited by the presence of sunlight. A large residential PV system might have 30 amps of short circuit current at full sun (compared to the 10,000 amps of utility supplied current), and a large commercial PV array may have 1,500 amps of available short circuit current

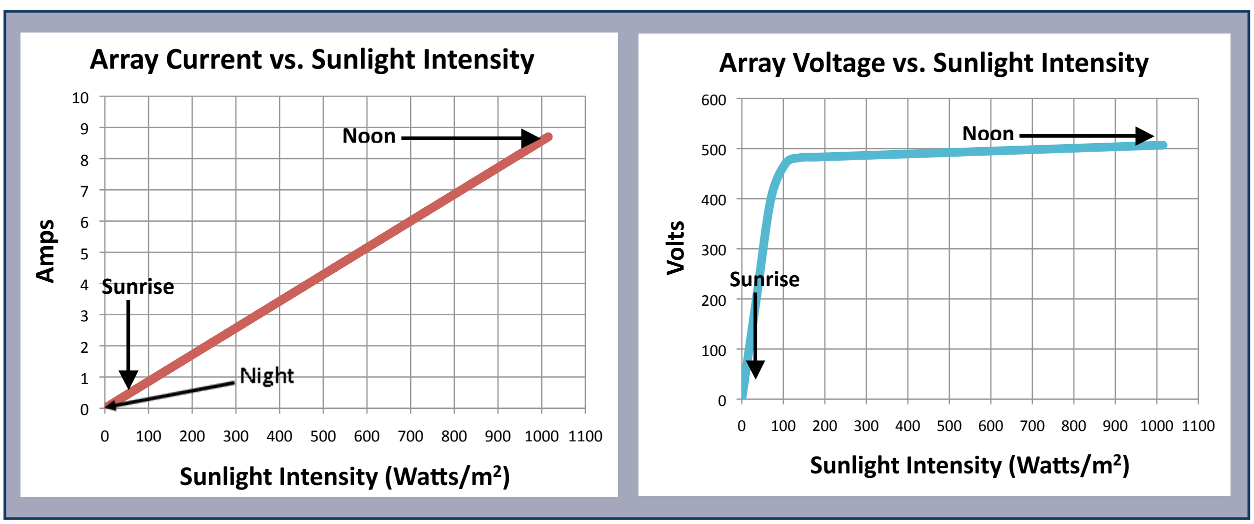




(compared to the 100,000 amps of utility supplied current). What this means for firefighters is that there is a significant difference in the hazard for arc flashes and arc burns between utility supplied current versus PV generated current. However, it does not mean that the PV electrical power is completely safe. It still poses many of the electrocution hazards that are discussed in this training.

Another important consideration for firefighters is that the voltage is very consistent during daylight hours. As soon as the sky is light and it is possible to easily see outdoors without artificial light, the voltage on a PV array will rise to the voltage it will operate at throughout the day.

Although current (amperage) is what causes damage to a person's body, the voltage is what drives that current through the body. The higher the voltage, the higher the amount of current is forced through the body in an electrical shock. The simple rule is that if it is possible to see outdoors easily without the need for artificial light, then the PV array is generating dangerous voltage.

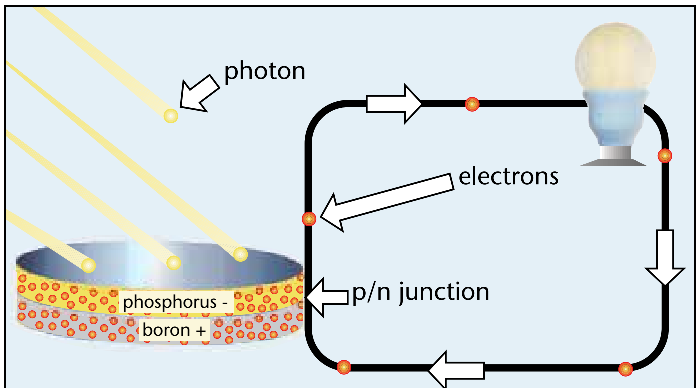


Photovoltaic designers have several options in regard to the fluctuation of energy throughout the day:

- Store excess electricity in a bank of batteries so that the electricity can be used when the sun is not shining. This design is typical of an off-grid system.
- Credit excess electricity generated back to the utility company. This is typical of a grid-tied system.
- Store electricity in the battery bank and credit excess electricity back to the utility grid. This battery back-up system ensures that the building owner will have enough electricity stored in case of a utility grid power outage (While battery back-up systems do exist, they are not common in the urban setting).

2.2 ANATOMY OF A SOLAR CELL

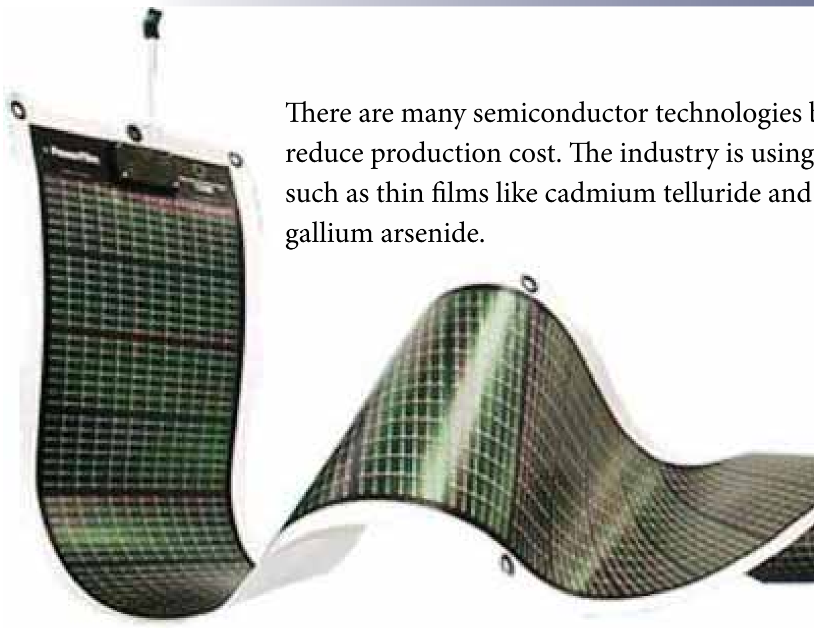
The individual solar cell is the smallest unit and the foundation of the PV system. There are two common types of PV cells: silicon and amorphous silicon. In both cases, a very thin slice of the semi -conductor silicon (about 1/100th of an inch thick) is layered along with boron and phosphorous in a process known as "doping". Boron, which is used for the positive layer of the cell, has an electron deficiency. Boron has room, or a hole, in the outer shell of the atom to add an electron. Phosphorus has an extra electron and is used for the negative layer of the solar cell. Photons from the sun energize and knock loose the extra electron in the negative layer which crosses the positive-negative (P-N) junction to fill the hole on the positive Boron side. This process generates approximately 0.5 volts per cell.



The Photovoltaic Effect

The composition of the silicon crystalline structure varies from manufacturer to manufacturer. The purest silicon structure employs the growth of a single crystal (monocrystalline) cut in to thin wafers. Multiple crystals cast together and sliced into thin wafers form polycrystalline structure seen in many solar panels.

All PV modules are made with multiple cells. However, some solar cells look very different from the squared crystalline silicon cells that are most common. Thin film semiconductors can be made from silicon, or other special semiconductors. These cells are most often organized in thin long lines on a PV module from ¼" to ¾" in width.



There are many semiconductor technologies being employed to improve PV efficiency and to reduce production cost. The industry is using and experimenting with many other materials such as thin films like cadmium telluride and high efficiency multi-junction cells that use gallium arsenide.

As stated elsewhere in this training, artificial light alone, in the form of scene lighting for nighttime operations, is insufficient to create dangerous current. PV cells may, however, generate miniscule amounts of electricity at night. In a recent study at the Sacramento Municipal Utility District, the Sacramento Fire District participated in an experiment to measure the amount of electricity generated at night or when exposed to emergency lighting systems. The results of this test are shown in Table 5.

Table 5: Results of Night Test, September 2007

			Foot Candles				
Test	Distance (ft)	Height (ft)	Tungsten	Mercury	Halogen	Volts	Amps
1	57	8				70	0.002
2	57	0				53	0.003
3	46	0	35	37	33	78	0.004
4	41	8	34	33.9	30.6	83.6	0.003
5	15	8	160	150	145	235	0.034

2.3 PHOTOVOLTAIC MODULES

Solar cells are encapsulated together within an anti-reflective glass and a plastic back cover. An aluminum frame typically protects the edge of the glass and provides a good mounting structure to fasten the module to a support structure.

When several cells are connected together in series and parallel the voltage and amperage is increased to achieve the desired electrical output. Photovoltaic cells connected together in this

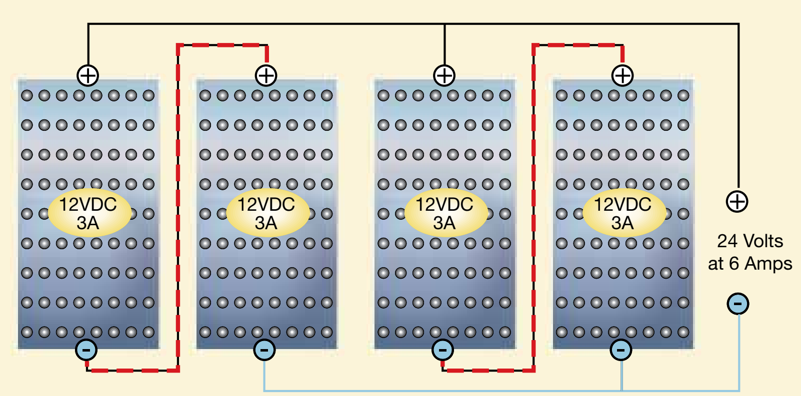
manner form a PV module. Weather-proof electrical connections are mounted on the back of the module for quick connections to other modules that comprise the PV array.

Modules come in a variety of sizes and rated outputs. A standard size module is approximately 5 feet by 3 feet, produces 20 to 40-volts, and consists of 50 to 72 solar cells. An average size crystalline module weighs between 30 and 50 pounds, most of which is the weight of the glass.

PV panels have no moving parts. An owner may need to occasionally wash dust, dirt, and bird droppings off the panels to keep them operating at peak efficiency. The panels themselves are completely weather proof, so there is little danger to those who perform this maintenance function.

2.4 PHOTOVOLTAIC ARRAY

One or more strings of modules forms an array. The modules are wired together in series to increase voltage, like the batteries in your flashlight. The strings are then wired together in parallel to increase amperage. Residential systems with outputs of 600 volts are common. The average household in California uses about 6,500 kilowatt-hours per year. A PV system in the three-to four-kilowatt range should adequately meet most residential electrical needs. A 20 module array, capable of generating over 4,000 watts, will weigh approximately 900 to 1,050 pounds. The weight of the system will be equally distributed over approximately 420 square feet of the roof, resulting in an increase to the roof weight load of approximately 2.5 pounds per square foot.



PV MODULES IN SERIES AND PARALLEL

2.4 PHOTOVOLTAIC TILES AND SHINGLES

Some residential PV systems are designed to be installed integrally with the roof tiles or shingles. These PV tiles or shingles become part of the roof system. This type of PV system is a form of "building-integrated" design. PV roof tiles match the depth of cement or clay tile roofs, and PV shingles do the same with composition shingles.

For building owners living in certain fire hazard severity zones, roofing systems must meet the California Building Code (CBC) for Class A roofing materials. PV tiles or shingles would also have to comply with this regulation. Some manufacturers of PV roofing tiles have a Class A rating.

2.5 RACK MOUNTED PHOTOVOLTAIC MODULES

The most common installation of PV systems is to fasten the modules to racks that are mounted above the existing roof surface. This method of installation is useful to ensure that the modules are oriented properly toward the sun and properly anchored to the roof. In fire hazard severity zones, PV modules that are mounted on racks above the roof covering do not have to meet the CBC Class A roofing requirement as long as the underlying roof is Class A.

2.6 INVERTERS

An inverter is used to convert the power generated by the PV module from direct current (dc) to alternating current (ac) so that the electricity can be used by the consumer or directed in to the utility grid. Inverters come in a variety of sizes and styles:

Micro-inverters: A single inverter that is next to or built into the individual PV modules. The micro-inverter converts the dc power at the module rather than at a single large inverter serving many modules.

System inverters: System inverters receive current and voltage from many strings or arrays. This type of inverter can be located on the roof near the array or inside the building in a location such as a utility room.

Inverters contain capacitors which store energy. Once de-energized, the capacitors begin to discharge their stored energy. However, they may be capable of electric shock until their voltage has diminished.

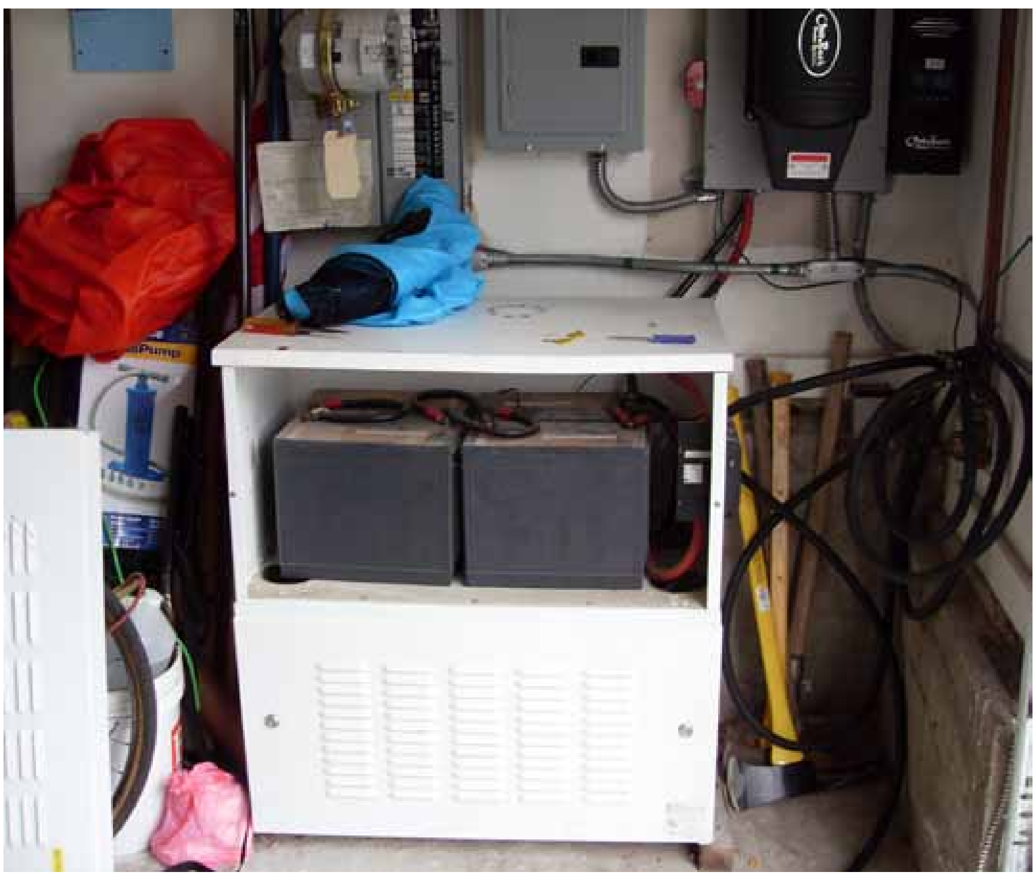
2.7 BATTERIES

Batteries are used to store solar-generated electricity. Batteries are used most frequently in off-grid PV systems, although batteries may also be used in grid-connected installations where the user wishes to have electricity available when local blackouts occur. Without batteries, a PV system cannot store electricity.

A battery is an electrochemical cell in which an electrical potential (voltage) is generated at the battery terminals by a difference in potential between the positive and negative electrodes. When an electrical load (appliance) is connected to the battery terminals an electrical circuit is completed.

A battery cells consists of five major components: electrodes, separators, terminals, electrolysis and a case or enclosure. Battery banks consist of several batteries wired together with "jumper wires" to achieve the desired voltage and amperage.

There are two terminals per battery, one negative and one positive. The battery may contain a liquid electrolyte; however, it can also be immobilized in a glass mat or suspended in a gel.



SECTION 3: OPERATIONS AND TACTICS FOR PHOTOVOLTAIC SYSTEMS

Terminal Objective

At the conclusion of this module students will be understand hazards and related factors necessary for operations involved in emergency response.

Enabling Objective

The student will be able to:

- Recognize PV systems
- Identify system locations
- Identify hazards with PV systems
- Perform size up
- Have knowledge of strategies and tactics

3.1 INTRODUCTION

Fire Department response, to buildings equipped with PV systems, has become more and more frequent. The increase in response to incidents involving PV is not because the systems are unsafe or hazardous in general, but because improved technology and lower cost and has made these systems a common addition to both new and existing buildings. Owners of residential, commercial and industrial occupancies see these systems as a source of "green" energy available at a greatly reduced rate when compared to the increasing cost of energy provided by public and private utility companies.

Firefighters need to practice and train for roof operations and ventilation techniques when photovoltaic systems are present.

Many firefighters view PV systems as a hazard because they're located on or near buildings and they generate electricity. As with any new technology we as firefighters encounter, the more knowledge firefighters have the more successful they will be in developing a successful tactics and strategies when operating at incidents involving PV systems.

Operating at incidents where PV systems are present may require firefighters to adjust their actions somewhat; however these adjustments should be similar to those that are necessary with many other types of electrical equipment or power generating sources.

If firefighters are able to identify the presence of PV systems and understand the hazards associated with the technology, they can then adjust their operations to mitigate the situation in the safest and most effective manner.

3.2 RECOGNIZING PHOTOVOLTAIC SYSTEMS

Recognizing the presence of PV systems in an emergency situation is one of the most important factors in providing safe and effective fire ground operations. In addition, recognition of these systems plays a major role in the strategy and tactics that will be employed to mitigate the emergency. Understanding PV system components and how the PV system functions will allow firefighter's to determine the best approach to the incident.

There are four general types of systems:

Ground Mounted

Roof Mounted

Building Integrated

Other (parking structures, trellises, etc.)

Recognition of PV systems on or near buildings can occur in a variety of ways. These include: Computer Aided Dispatch (CAD) files, run book information, fire company inspections, pre-plans and familiarity with areas of the response district in which "green" construction is prevalent. However, on-scene visual observation may be the first indication that the building is equipped with a PV system. A visual observation may not always be counted on because often PV systems cannot be seen from the street side or from ground level. Additionally, built-in PV and even roof mounted systems may be difficult or impossible to see at night.

A good "hot lap" or 360 degree view of the building on arrival increases the chance of spotting roof or ground mounted components. In some instances, the first information indicating there is a PV system on the structure may come from the crew assigned to the roof division.

Common indicators at ground level include exterior mounted electrical conduit, signage, inverter boxes, or switching that is not a normal component of the utility service box. Recognition and familiarity of these components can be enhanced by company-level training and study of these systems.

Firefighters working on the roof should communicate what they see and how the system could potentially impact the strategy the Incident Commander has chosen. The Division supervisor needs to assure crew safety and maintain situational awareness during operations near the PV system.

3.3. HAZARDS

Like other power generating devices, PV systems have certain hazards associated with the technology. Many of the same hazards associated with PV technology are present at incidents where PV systems are not present. This is because they are general electrical hazards not specific to PV systems. Like other electrical systems, the components are only hazardous if the system is compromised or directly involved in fire or the protective coverings on the components are damaged. The following lists some of the hazards associated with PV technology. Recognition and understanding these hazards will increase firefighter safety.

3.3.1 Electrical Hazards – Firefighter Electrical Safety!

The primary danger to firefighters working around an electrical system, and specifically PV systems is electrical shock. What makes electricity hazardous to firefighters is that it cannot be seen and can strike unsuspecting victims, sometimes fatally. A review of NIOSH after-incident reports reveals that even people with knowledge of electricity, such as electricians and linemen are killed every year in electrical accidents. The NIOSH reports (*available at http://www.cdc.gov/niosh/fire/*) also reveal that a number of firefighters are also killed and injured annually in electrical incidents.

3.3.2 Electric Shock and Burn Hazards

PV systems typically have the capacity to generate electricity in the range of 600 volts. This voltage, even at low amperages, is extremely dangerous to firefighters who may come in contact with it.

In general, electricity can cause a variety of effects, ranging from a slight tingling sensation, to involuntary muscle reaction, burns, and death. The physiological effects produced by electricity flowing through the body include:

AMP	Physiological Effect
6-30mA	Painful shock, muscle control is lost. This is called the freezing current or let go range.
50-150mA	Extreme pain, respiratory arrest, and severe muscular contractions, individual cannot let go. Death is possible.
1 to 4 amps	Ventricular fibrillation, muscular contraction, and nerve damage occur. Death is likely.
10 amps	Cardiac arrest, severe burns, and probable death.

Even at levels lower than 6mA, an involuntary muscle reaction could trigger a fall from a roof.

3.3.3 Resistance to Electricity

A "grounded" firefighter provides an excellent path for electrical current to go to ground. When this happens to a firefighter there are a number of variables that determine the degree of injury that may be sustained. These include:

- Amount of current flowing through the body
- Pathway of the current through the body (hand-to-hand or hand-to-foot)
- Length of time the body is in the current
- Body size and shape (muscle mass and body, the larger the person the more resistive)
- Area of contact (with conductive parts)
- Pressure of contact (of skin to the contacts)
- Moisture of contacts (sweaty skin will be more conductive than dry skin)
- Clothing and Jewelry
- Type of skin (callused hands opposed to back of hand)

Electrical shock is one hazard when working around electricity—burns are another. Burns that are caused by electricity include electrical, thermal and arc burns.

An arc-flash can occur when there is sufficient amperage and voltage and a path to ground or to a lower voltage. Arc-flashing is most common in ac circuits due to the presence of high amperage. Temperatures generated by arcing electricity can reach 15,000 to 35,000 degrees and can melt or vaporize metal in close vicinity. It can also burn flesh

> Important Note: Firefighters should not disconnect power by removing the electric meter from the meter box. Experience has shown that electrical arcing can occur and cause injury or death to the firefighter. Instead firefighters should lock out the main disconnect next to the meter and lock out/tag-out the meter box to insure that someone does not inadvertently re-energize the system

and ignite clothing at distances of up to 10 feet. The best way to prevent arc-flash hazards is to de-energize electrical equipment and circuits before approaching or touching electrical equipment.

3.3.4 Trip, Slip or Fall Hazards

PV systems are comprised of metal, glass, conduit and cable, all of which are slippery when wet. Some of these components protrude above the roof line or crisscross the space between rows of modules and may not be visible to firefighters in dark or smoky conditions creating a trip and fall hazard. Building integrated components, such as roof tile or shingle shaped PV modules may not be visible at all to a firefighter walking across a roof at night.

> Important Note: While you already know to avoid trip hazards posed by vent stacks, skylights and other obstacles on the roof, you now need to also consider walking and working around the photovoltaic array and in as many cases solar water heating and swimming pool heating collectors.

3.3.5 Increased Dead Load Roof Loads

A PV system installed during new construction or retro-fitted onto an existing building adds weight to the roof assembly. Light-weight constructed roofs are engineered to carry the building's design load under normal conditions. They are not designed to continue to support a load under fire conditions. The additional weight of a PV system, whether part of the original design load, or added as a retrofit, is likely to cause a roof to fail sooner.

3.3.6 HazMat—Firefighter Inhalation Hazards

Many hazardous materials used in the semi-conductor industry are also used in the construction of PV modules. These include: silicon, boron, phosphorus, cadmium, tellurium, arsenic, and gallium. Under normal conditions, these materials are sandwiched and sealed between a layer of glass and a plastic backing all of which are encased in an aluminum frame. During a fire involving PV modules the aluminum frame can easily deform or melt, exposing these materials to direct flame. The hazardous materials then become dissipated in the smoke plume and may be inhaled by firefighters not wearing breathing apparatus. Firefighters should also take caution when performing overhaul on and around PV

> Recommended Practice
>
> The inhalation hazards from the chemicals inherent in PV modules engulfed in a fire or explosion can be mitigated as long as firefighters wear their SCBA's and personal protective equipment during a structural firefighting and overhaul operations. It is the decision of the Incident Commander whether or not the emergency constitutes sheltering the population "in-place" downwind of the emergency. Fire or explosion emergencies involving large number of PV arrays, as in a commercial application, may necessitate evacuating downwind of the emergency.

modules and other electric components and continue to wear respiratory protection until the scene has been cleared by safety or hazardous material personal.

3.3.7 Battery Hazards

In some PV systems, batteries are used to store solar-generated electricity. Batteries are used most frequently in off-grid PV systems, although batteries are also used in grid-tied applications where the user wishes to have electricity available in the event of a power failure. Without batteries, a PV system cannot store electricity. Typically, several batteries will be arranged to form a "battery bank". The batteries in the bank are connected to each other with "jumper wires" to either increase voltage, or to increase amperage. The most commonly used batteries are lead acid. Lead acid batteries contain sulfuric acid that can cause harmful and explosive fumes. Once it has been determined that a building has a bank or banks of batteries, the IC and all personnel operating around the batteries should be notified.

During normal charging operations, batteries emit both hydrogen and hydrogen sulfide gas. Both of these gases are highly flammable. Hydrogen is lighter than air and hydrogen sulfide is slightly heavier. For this reason, spark producing equipment and open flames are not allowed where batteries are used or stored. Firefighters operating in and around battery storage areas should only use flashlights and other equipment approved for CLASS 1 atmospheres.

Another type of battery that is in use for PV systems is the Lithium ion battery. Lithium ion batteries are more efficient than lead acid batteries and therefore can take up less space. Lithium ion batteries contain flammable liquid electrolyte that may vent, ignite and produce sparks when subjected to high temperatures, damaged or abused (e.g., mechanical damage or electrical overcharging). Lithium ion batteries may burn rapidly with flare-burning effect and may ignite other batteries or combustibles in close proximity. Contact with the electrolyte in the lithium ion battery may be irritating to skin, eyes and mucous membranes. Fire will produce irritating, corrosive and/or toxic gases including hydrogen fluoride gas. PV modules themselves have no storage capacity. Inverters have capacitors which do store energy; however, the energy within the capacitors is discharged soon after power to the inverters is disconnected.

Inverters have capacitors that store energy which is discharged soon after power to the inverters is disconnected.

Important Note

Never cut into batteries under any circumstances! Even though the voltage generating PV system may be disconnected from the battery bank, the batteries themselves still have potential for electrical shock. If the battery is punctured by a conductive object, assume that the object may be charged.

3.4. SIZE-UP

Every firefighter is familiar with the term size-up. A good size-up is critical to starting the incident down the appropriate path to a successful conclusion. In the case of PV systems, it is extremely helpful to be aware of the presence of these systems prior to an incident. The reason for this is quite simple; the presence of these systems could possibly cause a change to strategy and tactics.

Firefighters should be aware of PV systems in their response district. Information about systems can be collected from a variety of sources:

- Company Pre-Incident Surveys and Prevention Inspections
- Fire Prevention Bureau records
- Building and Planning Department responsible for issuing the installation permit
- Visual observation

Doing a 360 degree size-up becomes increasingly difficult in dense housing areas. Firefighters should look for all visual clues including the sighting of this inverter in the open garage.

Information on buildings equipped with PV needs to be available to firefighters in the event of an incident. The information should be added to CAD files, included in the dispatch, included in the text on Mobile Data Computers (MDCs), and added as a symbol in run books. This pre-incident information will assist with on scene size-up and with determining the appropriate mode of operation, tactics and strategy.

Determining whether crews will be in offensive or defensive mode is based on many familiar factors, here are a few, in no particular order:

- Time of day—day or night;
- Life safety issues;
- Type of construction: Type I, II, III, IV, V;
- Method of construction—common, URM, balloon frame or engineered;
- Building features/height;
- Building density/spacing;
- Age of the building;
- Type of fire—structure fire, contents fire or PV system fire;

What to do in a PV Emergency

- Always wear protective clothing and SCBA
- Avoid Wearing Jewelry
- Use hand tools with insulated handles
- Locate Battery storage area (if applicable)
- Be aware that biting and stinging insects could inhabit the module frame and electrical junction boxes
- Lock out/tag out system disconnects should be located and disconnected.

- Volume/involvement of fire;
- Resources available;
- Lost time intervals between inception on-scene time.
- PV system present;
- The system is involved in the fire or is an exposure;
- The system or system modules are what's burning.
- Type of system—rack mount or building integrated;

The strategy will be determined after these and other initial size-up factors are assessed and an Incident Action Plan (IAP) is developed.

Just as information about potential fire behavior, building and roof construction is important to know during size-up, knowledge of the PV systems location and components will also be important factors in both pre-incident and "on-scene" size-up.

3.5 STRATEGY AND TACTICS

Strategy and tactics are the life blood of any incident. If these two pieces of the incident are not based on sound operational policy, training, and a well thought out approach to the problem, the entire incident will be compromised.

In incidents in which PV Systems supply the building with power, the firefighters on scene need to be trained in identifying PV systems and the methods to control them. In addition, they must know how to adjust their assessment of the incident involving PV to ensure appropriate actions are applied to the incident.

In any incident, the desired outcome is to always mitigate and/or control the situation in a safe and efficient manner. The strategy and tactics firefighters choose are critical to both the outcome and the safety of all members working on the scene.

The modules on fire at the Long Beach Convention Center were damaged in shipping and field repaired by the manufacturer's rep prior to installation.

3.5.1 Strategy

Generally, the strategic mode for a fire incident is either an offensive or a defensive attack. The Incident Commander might switch from one to the other but cannot accomplish both at the same time. Once the IC has completed the size-up and has chosen a strategy, the IC will assign the necessary tasks to the fire companies.

Fire fighters must quickly determine if the system itself is involved in the fire and if the system is able to be de-energized and notify the IC. The IC may need to adjust the strategy and potentially re-arrange the order of the tasks needed to deal with the PVs. If the IC chooses an offensive strategy it needs to be supported as any other fire with or without PV systems. However, the tactics used to support an offensive strategy may need to be flexible do to the presence of the PV system and the inability of firefighters to de-energize all of the electrical equipment.

The strategy selected by the IC should have "trigger points" that will allow the IC to assess the fires impact on the structure and change strategy if a delay in the attack caused by the PV system results in excessive lost time.

Another factor to be considered by the IC is the presence of the sun. A fire occurring during nighttime will allow for a different strategy than a fire during daylight. However, if the incident proceeds past sunrise, the IC must be aware that the sunlight will cause the panels to become energized and the initial strategy may need to be adjusted accordingly.

3.5.2 Tactics

Tactics are generally based upon the selected strategy and chosen objectives. As with the strategy, the implementation of tactics may be affected by the presence of a PV system. In buildings equipped with PV systems, control of the utilities must include control of the PV system as well as the local utility supplied power. In addition to de-energizing equipment powered by the local utility, the Utility Group must also de-energize electrical circuits leading from the PV system. The Utility group should locate and disconnect any and all switches in the PV system,

The Utility Group should watch for visual indicators like these warning labels to identify the existence of additional electrical power sources to the building.

including switch-gear on the roof, switches on either side of an inverter and any switches in the connection to the building's main electrical system.

In PV systems, there is always the possibility of energized conductors within conduit during daylight; therefore, knowledge of the location of PV system conduit is important to firefighters performing tasks such as ventilation and overhaul. When possible, the Utility Group should also determine the location of all electrical conduits leading away from the array or otherwise connected to the PV system. Prior to overhaul, the Utility Group may consider marking the PV system conduit with bright spray paint or other means that will be understood by other firefighters working around the conduit.

Aggressive fire operations are important whether or not a PV system is present.

If the system is "off-grid," the Utility Group should determine if the building is served by other electrical sources in addition to the PV system. These may include fuel powered, wind and hydroelectric generators. The Utility Group should attempt to isolate all of the sources, including the PV, by locating the system controls and opening the main disconnects.

A Ventilation Group or Roof Division should advise the IC if the PV array is going to impact the crew's ability to ventilate the structure effectively from above. If vertical ventilation cannot be accomplished, the IC needs to be notified immediately so that strategies and tactics can be adjusted. Changing to another form of ventilation requires coordination with the IC and interior crews.

3.6 COMMUNICATIONS

Communications have been proven time and time again to be an important factor in any incident; too much or too little communication may be detrimental to the overall incident. Within the Incident Command System, "Unity of Command" allows for each person to report to only one designated supervisor and "Span of Control" limits the number of people reporting to each supervisor. This communication model allows for direct, clear communication of information and events and contributes to the success of any incident.

Good fire ground communications have some very basic and specific characteristics that should always be used during an incident. Fire ground communication should be clear, concise and informative. Some of the communications normally heard on the fire ground frequency are:

- Initial size-up
- Initial mode of operation
- Tactical assignments
- Command changes
- Primary and secondary search findings
- Progress up dates
- Time intervals
- Accountability—Personal Accountability Reports (PAR), Conditions Actions Needs (CAN), Personnel Position Progress Needs (PPPN), etc.
- Hazard notifications
- Emergency Traffic and broadcasts
- Changes in operational mode

Communications at incidents that involve PV systems should not be different than communications at any other incident. However, some of the communications will involve terms and phrases found throughout this training program that may be specific to the PV systems and how the system will impact the overall operation. Training officers, company officers and firefighters should include PV scenarios in training so that terms such as PV, BIPV, array, inverter, ac, dc and other terms used when describing components of a PV system are familiar to firefighters and can be used during fires when PV systems are present.

3.7 FIRE GROUND OPERATIONS

Offensive fire ground operations involving any structure with a PV system will require personnel to take certain precautions. Common PV hazards include;

- Electric shock
- Hazardous atmosphere
- Explosion/arc-flashing
- Collapse
- Trip, slip or fall

> During day time incidents involving buildings with a PV system it is important to remember that the panels are always "Hot"

While these hazards aren't unusual to firefighters operating on the fire ground, they may be accentuated by a PV system. The existence of a PV system will not necessarily prevent the initiation of offensive tactics; the system may have no impact on the fire whatsoever. Tactics necessary to perform rescues, exposure protection, confinement, extinguishment, salvage, ventilation and overhaul can and should still be initiated within buildings that have PV systems. However, the possible additional hazards that may be created by a PV system should always be considered before undertaking any of these operations.

Recognizing the hazards, the use of protective gear, and avoidance of the PV system components will be fire fighters best defense when working around PV systems. However, the possible additional hazards that may be created by a PV system should always be considered

As discussed in previous sections, PV systems may not be obvious to firefighters approaching a building from the street level. In many modern subdivisions building integrated PV, such as PV shingles or building sidewalls may make the PV system difficult to detect. In densely populated urban areas with little or no access to the sides and rear of a structure, the ability of first arriving companies to complete a 360° size-up will be limited. Roof operations personnel or the Utility Group may be the first to locate a PV system. Early recognition of and communications about the PV system by firefighters operating on the fire ground is imperative. This information will aid the Incident Commander and other personnel in establishing a strategy, determining risk, and prioritizing their tactical objectives.

During day time incidents involving a PV system, it's important to remember that the panels are always producing energy. The Incident Commander should assign a Utilities Group to locate and

Firefighters should never "pull" the electric meter as a way of shutting down the power to the building.

Residential PV Disconnect with Labeling. The interior of the disconnect box shows how lines are disconnected when the knife switch is activated.

de-energize all of the PV components, along with any other utility supplied electrical service serving the building in order to reduce the risk of electrical shock to firefighters. The power disconnects for the PV system components should be located and placed in the "Off" position, and "Lock out/Tag out" measures used. By code, these components should have specific signage or labels designating their location, however, this may not always be the case.

3.7.1 Roof Operations

There are few more effective ways to improve interior conditions for victims and firefighters inside a structure fire than ventilating the structure. Roof operations can aid in rescue opportunities in light wells and in the rear of a structure, and provide the Incident Commander (IC) with valuable fire condition reports. The Roof Division or Ventilation Group may often be the first to determine exactly what is on fire.

Are the PV panels or electrical components burning, or is it a structure fire? Early recognition of the problem and notification to the IC are key to the development of an Incident Action Plan (IAP).

A PV array built onto a roof may affect ladder placement and use; requiring fire crews employ other methods to gain roof access. On buildings with a sloped roof, the PV panels will normally be found on the South and West facing sides. Commercial and residential structures with flat roofs may have a large portion of the roof covered by the PV array. Ground ladder placement, instead of an aerial ladder, may be needed to achieve the best access/egress point for the operation. Even though there are hazards to fire fighters performing roof operations in close proximity to PV systems, they most likely will not prevent crews from completing their tactical objectives.

If vertical ventilation cannot be completed the Incident Commander must be notified immediately so that the incidents tactical objectives can be reevaluated and changed

A roofing system, with two layers of composite shingles and a PV array may be compromised when affected by fire.

One of the primary goals of roof operations should be to determine if the PV system components themselves are on fire, or are the PV components being impinged by fire. There are toxic inhalation hazard associated with burning PV modules due to the chemicals used to manufacture the modules. Firefighters can be protected from these hazardous chemicals with the use of a Self Contained Breathing Apparatus (SCBA). Once roof operations are started, firefighters should quickly complete their objective and safely exit the roof. Any additional time spent on a roof with a PV system will only subject personnel to additional hazards.

If the PV system components experience a mechanical failure, or have been compromised by fire, arcing or faulting may occur. This electric shock hazard may prevent firefighters from being able to work safely on the roof and may cause operations to be abandoned and strategic and tactical objectives reevaluated.

Additionally, the building's roof structure should be evaluated determine the collapse potential due to the added weight placed on the roof by the PV system. Light weight truss or wooden I-beam construction could result in a collapse if the fire has sufficiently degraded the roof's structural components. In general, rooftop PV modules are not very heavy. The additional weight added to a structure by a PV system is generally 2.5 to 3.5 lbs/sq. ft. This is far less that the 10 lbs/sq. ft. engineered roofs are usually designed to carry. By comparison, a single layer of 30-year composition shingles is roughly 4 lbs/sq. ft, and covers 100% of the roof surface, while a PV system will usually only cover a portion of the roof.

The number of roof layers under a PV system is important to fire crews on the roof. By code, PV systems should not be installed onto roofs with more than 2 layers of composite roofing material due to weight limits. If the structural stability of the roof is in question, remove some roofing material and perform a quick inspection. Firefighters should consider a roof with a PV array mounted over 2 layers of composite shingles as highly compromised when the roof structure is impinged by fire. A roof load can also be negatively affected due to a PV array's ability to trap snow or other debris. Snow and debris will add to the dead load on the roof and increase the possibility of collapse. On windy days, rooftop arrays can act like sails producing large amounts of force pulling against the roof structure under the panels. The Incident Commander and roof personnel should evaluate the structural hazards the array's present and make the determination to abandon roof operations if necessary.

PV panels, mounting systems, and conduit present a trip, slip and fall hazard to firefighters. This is particularly true under two circumstances:

- BIPV shingles built into a sloped roofs shingle system can be extremely slippery and hazardous to firefighters walking on them.
- Because PV arrays on commercial structures often cover large portions of the roof, there may be very little clear space on which to walk.

Night operations, weather and smoky conditions will only compound these issues. Crews must move and work with additional caution because of these hazards. If possible, the tactical operations to be carried out on the roof should be done away from all PV components. Roof personnel may need to reevaluate their position and access the roof from an alternate location. Emergency egress points need to be determined early in the operation. Avoid positioning you and your crew so that the PV system is between you and your escape route. Situational awareness is key when operating near PV components.

Because PV panels continuously produce electricity during daylight, it may prove difficult to remove all burning or smoldering materials from under or around the panels without subjecting crews to an electric shock hazard. Removal of the panels, unless done by a qualified PV technician or electrician, is not recommended and strongly discouraged. Firefighters may find it necessary to contain the fire and prevent its spread until the panels can be safely removed. It is strongly recommended that fire departments maintain a list of several licensed solar power installers or electricians that are willing to assist their department in securing or de-energizing PV systems and components in the event of an emergency.

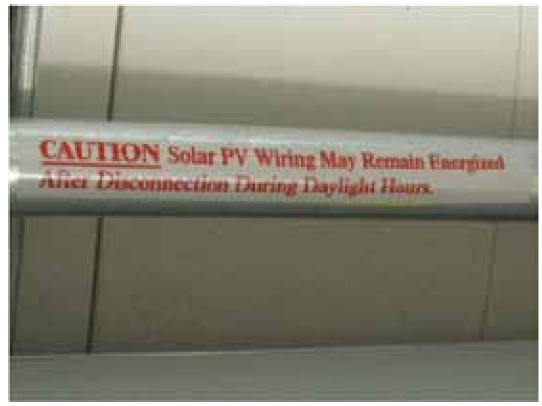
3.7.2 Ventilation Operations

PV panels located on the roof may present a significant obstacle for fire fighters assigned to ventilate. Vertical ventilation can be delayed or prevented because of the size and location of a building's PV system. Cutting a ventilation hole directly over the fire will not be possible if the area is covered by a PV array or it's structural support frame. Ventilation operations must be limited to those areas of the roof that are clear of the PV array and other components. If ventilation operations have to be done in close proximity to a PV system firefighters must be sure they do not cut or otherwise damage any of the system components. If possible, a safety officer

> Not only are PV modules slippery when wet, they are not designed carry weight and therefore should not be walked on by firefighters.

should be established to oversee operations when firefighters are work in close proximity to the PV array.

PV system conduit containing energized conductors on the roof deck and in attic spaces poses a serious shock hazard to firefighters performing ventilation. Crews must work together to prevent damage to any PV components with their tools or actions. If vertical ventilation cannot be completed, the IC must be notified immediately so that the incident strategy and tactics can be reevaluated and changed, if necessary. Horizontal or positive pressure ventilation may have to be used to perform ventilation if the roof is obstructed by the PV array or other system components.



Traditional "Hot Sticks" used by the fire service are not recommended because they are designed to test for ac power only.

3.7.3 Interior Operations

Interior fire ground operations may also be affected by a buildings PV system. Energized system components located inside the building may create an electric shock hazard for interior crews. PV system conduit and wiring can be located in any portion of the building, including equipment rooms, closets, garages and attic spaces. Personnel must avoid coming in contact with these hazards and notify the Incident Commander and other firefighters of their location. When engaging in firefighting tactics on structures that may have energized PV systems, the issue of whether or not to apply water is an important tactical decision. If possible, firefighters should avoid directing hose streams directly onto energized PV system components and use or dry chemical extinguishers, if possible. If water is used, the following recommendations from Pacific Gas & Electric's (PG&E) Emergency Responders Training Program[2] should be followed:

- There should be a minimum of 100 psi at the nozzle.
- The fog spray should be set at 30 degree fog pattern at 100 psi.
- Firefighters must be at least 33 feet away from the energized source.
- Straight streams or foam should not be used. They are excellent conductors and put the responder at great risk.

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[2] *Source: "Responding To Utility Emergencies"; Pg. 63, 2004; Michael Callan, Public Safety Program Mgr, PG&E*

> The Utility Group, when assigned, should be tasked with locating and disconnecting all power sources supplying the building

Further, the PG&E recommendations point out that the electrical resistance of the ground can change due to water runoff, thereby creating an additional hazard to firefighters.

Fire ground water usage on or near PV system components should be based on conditions found at the time of the incident and department SOPs. If water has to be directed on or near a PV system a 30 degree fog pattern at 100 psi should be used in order to prevent any electric current from traveling upstream toward firefighters applying the water. Firefighters also need to be cautious of the electric shock hazard created by puddles of water.

The Utility Group, when assigned, should be tasked with locating and disconnecting all power sources supplying the building. These could include PV systems, electrical utility service, fuel, wind and hydroelectric generator sources. These disconnects may be numerous and in multiple locations. PV system and other electrical source disconnect switches must be located and "locked out".

It is important to remember that the PV modules and arrays will still produce electricity to the inverter during daylight hours and that an electric shock hazard exists. Traditional energy sensing "Hot Sticks" used by the fire service are not recommended because they are designed to test for ac current and voltages only. Some department members may have enough experience with electricity to use an ac/dc multi-meter to confirm that power isolation has been achieved, otherwise, it is strongly recommended that firefighters wait for the arrival of a qualified solar technician or electrician.

If present, battery banks can also present toxic and explosion hazards for interior firefighting crews. The fumes and gases generated by batteries exposed to fire are corrosive and flammable. Spilled battery electrolyte can produce toxic and explosive gasses if it comes in contact with other metals. Because of these hazards, water as an extinguishing agent should be avoided if possible. or dry chemical extinguishers are strongly recommended for extinguishing fires involving lead-acid batteries.

Firefighters should never cut battery cables as a means of disabling a bank of batteries. Even after the batteries have been isolated from the electrical generating system, the batteries still have electric shock potential. Crews must wear full personal

Incidents involving PV systems are unique, in that energized components may remain within the structure or on the roof even after all common power has been disabled

protective equipment (PPE) and SCBA when dealing with an emergency involving PV system battery banks. Due to the high degree of hazards associated with these batteries, the IC may have to stop interior operations and reevaluate the strategy until the hazardous atmosphere can be tested and mitigated through ventilation. Hazmat teams with specific protective clothing may need to be called to the scene to aid in operations.

3.7.4 Search Operations

Search and rescue is the first tactical priority firefighters when approaching any fire scene. Searching under extreme heat and smoke conditions, often in zero visibility and with no hose line for protection, makes this one of the most dangerous tasks done on the fire ground. Search teams conducting primary and secondary searches for victims may unknowingly come in contact with energized PV components that may have been damaged by the fire and lay exposed. The location of the components must be immediately relayed to the IC and all personnel working on scene, and disconnect switches turned “OFF”.

3.7.5 Overhaul

Overhaul is an important task performed during the later stages of every fire in order to ensure complete extinguishment and prevent rekindle. Firefighters engaged in overhaul operations need to be aware that a building’s PV system conduit can be hidden behind walls and in attic spaces. In buildings equipped with PV, the use of tools to breach walls and ceilings to search for fire extension must be performed with extra caution. This is particularly true during daylight hours when some PV components are energized. Whenever possible, the IC should delay overhaul until there is competent confirmation that the PV system has been “de-energized.”

Once the fire has been extinguished personnel safety is still a critical concern and often can be taken for granted as the incident enters the stabilization phase of the IAP. Many fire ground injuries and even fatalities have occurred well after the fire is out. In recent years, a fire investigator was killed by the collapse of a freestanding chimney several days after fire companies left the scene.[3]

[3] *“Firefighter Fatalities in the United States in 1999,” National Fire Data Center, U.S. Fire Administration, July 2000.*

> NFPA 1561
>
> 5.3.24 The incident commander shall be responsible for the continuation, transfer, and termination of command at an incident.
>
> 5.3.25 The incident commander shall order the demobilization of resources when appropriate.
>
> 5.3.26* The incident commander shall provide for control of access to the incident scene.
>
> 5.3.27 The incident commander shall make appropriate incident status notifications to key people, officials, and the agency administrator.

At the conclusion of an incident, demobilization and termination efforts should be directed at leaving the property in the safest condition possible.

An overhaul focused size-up and risk-benefit analysis should be conducted. Incidents involving PV systems are unique in that components may remain energized within the structure or on the roof even after all utility supplied power has been de-energized. Along with a structural stability assessment, hazard identification and the marking of any potentially energized areas should be a priority. Investigators, building officials, property owners, and/or building maintenance engineers should be properly notified of any hazards that may exist. A qualified PV technician or electrician should be called to the incident to de-energize any system that has been compromised or creates a hazard.

Transferring scene safety and security to an appropriate local, municipal authority may be an option if the fire department is unable to quickly secure the assistance of a qualified PV technician or electrician. All hazards should be appropriately marked or barricaded. Structures should not be released by any agency until all obvious hazards have been eliminated.

Terminal Objective

At the conclusion of this module students will be able to recognize common attributes & hazards of a typical residential PV system.

Enabling Objective

The student will be able to:

- Identify residential PV system components
- Identify unique hazards associated with residential PV Systems
- Identify Strategic & Tactical Considerations

4.1 INTRODUCTION

This section will address the installation of PV systems on residential structures. For firefighters, these will be the most common locations in which PV systems are found. Residential applications discussed in this section include one and two family dwellings and townhouses. Although these systems will most commonly be rooftop installations, they may be ground mounted or mounted on a stand-alone structure, such as a trellis or arbor.

Identifying the presence of a PV system at a residence is a primary objective for responding firefighters. The following is list of visual indicators that may help firefighters determine the presence of a PV system:

- Visualization of the array upon on arrival.
- Visualization of the inverter. The inverter may be mounted on an exterior wall (often close to the main electrical panel), garages, or even in a basement.
- Labeling on the main electrical panel indicating the presence of the PV system.
- Exposed or concealed conduit runs on the roof, inside walls or in the attic. Exposed or concealed metallic conduit on the inside or outside of a residence is a strong indicator of the presence of a PV system.

The size of most residential systems will range 3kw to 8kw, with operating voltages up to 600 volts dc at less than 30 amps. While PV systems are capable of generating their maximum voltage in low light conditions, such as at dawn or dusk, the amperage, or current, varies throughout the day. Amperage output increases as the sun rises in the sky and decreases as the sun sets. This means that at about noon on a sunny day, the PV system is generating its maximum power.

> In extraordinary circumstances, where all other tactics or options have been exhausted and the PV panels must be removed. Care should be taken to use non-conductive tools, since the modules and frames may still be energized. Damaged systems should not be touched without verifying whether or not the system is energized. Specialized tools may be required to disconnect wiring. Firefighters should consider containing fires within PV systems rather than removal due to the inherent hazard and lack of electrical safety training afforded to firefighters.

While the majority of residential PV systems that firefighters encounter may be grid-tied, the presence of a backup electrical generating system must be considered. This could be either a battery bank in the garage, or out-building, or a generator. Determining the presence of batteries or a backup generator is often accomplished when the lights or appliances remain on after the main service disconnect is shut off. The additional disconnects for other electrical sources may be numerous and in multiple locations. PV system and other electrical source disconnect switches must be located and "locked out" in order to assure firefighter safety. (Refer to Section 6 for further discussion of battery systems.)

Installation of roof integrated PV system.

STRATEGY AND TACTICS

Following a good size-up of the incident and the determining that it is not the PV array or other PV components that are on fire, the choice of a strategic mode should be made by the IC following normal department SOP's. Tactics, like the strategy, should also be based upon normal standard operating procedures. What the presence of a PV system may change for firefighters at residential fires is their ability to ventilate the building and the complexity of utility control.

The presence of an array on a roof may affect laddering locations, access and egress. PV modules should not be stepped on due to their potentially slippery surface if wet. While they are designed to sustain a strong impact, they are not designed to support the weight of a person walking on them. Roof ladders should never be placed across an array. Building integrated PV (BIPV) on a tile roof may be hard to see at night, are very slick, and could easily result in a fall. Ladder placement may need repositioning once a PV or BIPV system is discovered.

Vertical ventilation is one of the tactics that may be employed. The coordination of the venting operations on a building equipped with a PV system is a key component to the fire fight because the ventable area of the roof may be limited. Generally, firefighters ladder in the uninvolved area of the structure. However, this may not be possible due to the location of the PV array. Once the ladders are placed, an aggressive, coordinated opening should be made as close to the fire as possible. Coordination with the interior crews is important so that the opening is not made behind the crews, and so they are in a safe position if the ceiling is pushed down from above. Ideally, coordination with the Utilities Group is also needed because the Utilities Group may have some indication of where the PV system conduit is located.

Power saw and axe usage by the ventilation crew is of concern if the wiring run cannot be determined. Firefighters should give consideration to the depth of their cuts because the PV system conduit/wiring may be attached to the underside of the roof framing members. A good understanding of roof construction and cutting techniques is vital to the safety of the firefighters when the building is equipped with a PV system.

In cases where the conduit run is in the attic or walls, care should be taken when pulling wall or ceiling material to avoid contact with the PV conduit. Should the conduit become separated at its joints, it may no longer be grounded and contact by a firefighter may result in an electrical shock.

When the fire involves only the PV system and not the building, the priorities change to protecting the structure from involvement. Firefighter's initial efforts should be directed toward preventing the fire from

Fire departments should test their salvage covers on a PV array in advance of an incident to determine if they will successfully block light transmission.

spreading to the roof or other nearby building components. If a portion of the array or other an electrical component is involved, or dry chemical extinguishers, or a 30° fog spray stream at 100 psi are the methods used to extinguish or confine the fire. Firefighters may have to continue their efforts to confine the fire to the system components for an extended period of time until a qualified PV technician arrives and assists in de-energizing the electrical equipment. Depending on the degree of damage and involvement of the system, there may be no protective grounding present, so contact with the array should be avoided.

The exclusion of light to de-energize the PV system is a tool that may be considered by the IC for residential PV systems. Testing conducted with both salvage covers and black plastic sheeting has proven to completely reduce the amount of energy produced by the PV system once it's fully covered. Salvage covers used for this purpose should be dark in color. White or other light colored salvage covers should not be used as they permit enough light transmission to allow the system to continue to produce energy. Salvage covers or black plastic sheeting must be positively secured in place over the array. Uncovering of the array by the wind or otherwise will cause the system to produce energy. Fire departments should test their salvage covers on a PV array in advance of an incident to determine if they will successfully block light transmission.

At the conclusion of an incident, demobilization and termination efforts should be directed at leaving the property in the safest condition possible. An overhaul focused size-up and risk-benefit analysis should be conducted. Incidents involving PV systems are unique in that components may remain energized within the structure or on the roof even after all utility supplied power has been de-energized. Along with a structural stability assessment, hazard identification and the marking of any potentially energized areas should be a priority. Investigators, building officials, property owners, and/or building maintenance engineers should be properly notified of any hazards that may exist. A qualified PV technician or electrician should be called to the incident to de-energize any system that has been compromised or creates a hazard. Transferring scene safety and security to an appropriate local, municipal authority may be an option if the fire department is unable to quickly secure the assistance of a qualified PV technician or electrician. All hazards should be appropriately marked or barricaded. Structures should not be released by any agency until all obvious hazards have been eliminated.

SECTION 5: COMMERCIAL LARGE AND SMALL

Terminal Objective

At the conclusion of this module students will be able to recognize common attributes and hazards of typical commercial photovoltaic systems.

Enabling Objective

The student will be able to:

- Identify commercial system components
- Identify unique hazards associated with commercial PV systems
- Identify strategy and tactical considerations

5.1 INTRODUCTION

Although the number of residential sites greatly exceeds the number of commercial installations, there is a similar amount of PV (in total Megawatts) installed in small and very large commercial installations. This is because commercial systems tend to be larger than residential systems. Commercial installations include a broader variety of applications, given the greater variety of commercial structures and applications for solar. The most common systems are rooftop installations, but other installations may be located as a ground mount or mounted on a stand-alone structure, such as a parking shade cover.

Identifying the presence of a PV system is a primary objective for firefighters. Early recognition of the presence of a PV system will aid in the development of strategic and tactical goals. Unlike residential systems, where the arrays are often visible from the ground, a large percentage of commercial systems are installed on flat roofs and will not be visible from the ground. There may be large installations in communities that the local fire department is not aware of. Communication between the fire department and the permitting agency can help identify these systems in the community.

During size up, identifying a commercial system can be accomplished through the following components:

- Labeling on the main service panel upon arrival and PV system disconnecting means.
- Surface mounted conduit coming down from the roof along the side of the building.

- Visualization of the inverter. The inverter may be mounted on or near an exterior wall (often close to the electrical service entrance) or in electrical rooms.
- Visualization of the array on arrival either from the exterior or after sending a company to the roof

The energy output for commercial systems will generally be between 10 kilowatts (kW) to 2 megawatts (MW). Although the power output of individual PV systems varies, in general the size of the area that these large systems cover is as follows:

10 kW .... 1,000 square feet

1 MW .... 10 acres

5.2 STRATEGY AND TACTICS

The presence of a large array on the roof may affect roof operations, including ladder placement, access/egress, and vertical ventilation. Depending on whether consideration has been given during design of access pathway to skylights and other venting opportunities, the presence of the array is likely to increase the amount of time needed to perform vent operations. Fire fighters should not step on modules and should be aware of the trip, slip and fall potential around PV racking systems, conduit and the modules themselves. Many systems include narrow walkways between rows for maintenance access. While these rows are not intended for firefighter access, they may provide an alternative means of egress.

An important consideration while conducting operations on a roof with a PV system is the added weight to the roof. Although it is difficult to quantify how much the weight of the PV system will affect the potential for roof collapse, it must be factored into the initial size up, strategy, and tactics. The type of roof construction, roof material and area covered by the array should be considered when crews first access the roof. As previously stated, it is common to have acres of roof area covered by modules on large commercial structures.

PV systems mounted on low-sloped roofs employ a variety of mounting techniques. While some systems are mounted on racks that are welded or bolted to the roof structure, the majority of roof-mounted systems are mounted on what are called "ballasted" mounting systems. These ballasted systems use a combination of the weight of the PV modules and concrete ballast to keep the array in place on the roof. The weight of these ballasted systems is typically limited to 5 lbs/ft_2. In addition, the aerodynamics of the array is evaluated and wind spoilers are often employed to prevent uplift on the PV array. In locations

where wind loads exceed the ability of the ballast and wind spoilers to hold the array, anchors are welded or bolted to the structure to provide an additional means to hold the PV array on the roof structure.

If the PV system is the source of the fire, then protection of the exposed structure is the primary concern. During daylight hours crews should consider all PV system modules and arrays energized and fight the fire as they would any other electrical fire. Crews should use or dry chemical extinguishers on any potentially energized PV component. If the roof material is on fire, a 30° fog stream at 100 psi can be used to prevent further spread of the fire without risk of shock to the firefighters. Firefighters, however, must be cautious of water pooling on the roof that could become energized. Care must be taken to avoid unnecessary contact with potentially energized PV components until they can be isolated and confirmed de-energized.

Depending on the level of damage to the system, the connection to "ground" may have been lost, contact with the PV system components should be avoided until the system is determined to be de-energized. Modules cannot be isolated during daylight hours and must always be considered energized. Firefighters working on and around PV systems should only use non-conductive tools, since the modules and frames may still be energized. Burning PV modules produce toxic vapors. Firefighters must wear full PPE and SCBA due to the toxic inhalation hazard produced by these burning components. Crews should work upwind of the smoke whenever possible.

> In extraordinary circumstances, where all other tactics or options have been exhausted and the PV panels must be removed. Care should be taken to use non-conductive tools, since the modules and frames may still be energized. Damaged systems should not be touched without verifying whether or not the system is energized. Specialized tools may be required to disconnect wiring. Firefighters should consider containing fires within PV systems rather than removal due to the inherent hazard and lack of electrical safety training afforded to firefighters.

Damaged systems should never be touched without verifying whether or not the system is energized. Firefighters should never cut the wiring in a PV system. Specialized tools may be required for disconnecting the module wiring. Firefighters should consider controlling fires within PV systems rather than removal due to the inherent electrical hazard. Mounting systems, modules, and conduit should not be disassembled, damaged or removed by firefighters operating on the roof until all of the PV system's components are isolated or de-energized by a qualified PV technician or electrician. Firefighters should limit their activities to containment of the fire until it can be confirmed that the system is isolated or de-energized.

At any incident where PV is present the IC must designate a "Utilities Group" early to aid in locating and disabling all of the buildings utilities and PV system components. This can greatly decrease the electric shock hazard to all crews operating on the fire ground. Firefighters must remember that all PV components must be considered "HOT" during day light. Additionally, in large commercial systems, there is likely to be several arrays. Firefighters must be aware that if a single array is isolated, all of the others will most likely remain energized. Care must be exercised when operating the other energized arrays.

At the conclusion of an incident, demobilization and termination efforts should be directed at leaving the property in the safest condition possible. An overhaul focused size-up and risk-benefit analysis should be conducted. Incidents involving PV systems are unique in that components may remain energized within the structure or on the roof even after all utility supplied power has been de-energized. Along with a structural stability assessment, hazard identification and the marking of any potentially energized areas should be a priority. Investigators, building officials, property owners, and/or building maintenance engineers should be properly notified of any hazards that may exist. A qualified PV technician or electrician should be called to the incident to de-energize any system that has been compromised or creates a hazard. Transferring scene safety and security to an appropriate local, municipal authority may be an option if the fire department is unable to quickly secure the assistance of a qualified PV technician or electrician. All hazards should be appropriately marked or barricaded. Structures should not be released by any agency until all obvious hazards have been eliminated.

SECTION 6: GROUND MOUNT AND RURAL SYSTEMS

Terminal Objective

At the conclusion of this module students will understand what are ground mounted photovoltaic systems, hazards, size-up, strategy and tactics and the limited resources available in rural areas.

Enabling Objective

The student will be able to:

- Identify and learn what is ground mounted and where they may be located
- Identify hazards for ground mounted and rural PV systems
- Size-up, strategy and tactics may be different for ground mounted and rural areas compared to roof mounted PV systems

6.1 INTRODUCTION

Ground mounted PV systems generally stand alone and are supported by a framework that sits directly on the ground. These systems can vary in size from small 3 kilowatt (kW) system for a residence, up to several megawatts covering acres of land. Although the power output of individual PV systems varies, in general the size of the area that these ground mounted systems cover is as follows:

3 kW.................. 300 square feet

100 kW............. half acre

1 MW .... 10 acres

Ground mounted systems are used as trellises, car ports, shade structures, pedestrian walkways and other free standing structures with no purpose other than to support the PV arrays. Ground mounted PV systems are a viable alternative for facilities with sufficient land on which to place the arrays. Many farms, schools, waste water treatment plants, residences with large yards or open acreage, and many other types of facilities opt for a ground mounted installation rather than a roof mounted installation. You need to be aware that a ground mounted system may be supplying a facility that is located a significant distance from the PV installation, to the extent that it may even be difficult to determine the location of the supplied facility.

Photo is representative of these ground mounted systems, and depicts the nature of the array being remote from the facility.

A ground mounted array consists of the same categories of equipment as a typical roof mounted system, with the addition of a structure with the primary purpose of supporting the solar array. Ground mounted systems typically supply power to a nearby facility, and connect to the electrical system of that building. PV systems may be very low to the ground, or may be mounted atop a taller structure specifically designed to support the PV array. The inverters and dc combiner boxes could be located at the ends of a row of arrays or in between rows of arrays. The dc conduit/wiring to the combiner boxes may be running in between the rows of arrays.

6.3. HAZARDS

Ground mounted PV arrays pose a few specific hazards in addition to those posed by roof mounted systems. Some of the additional hazards firefighters need to be aware of when combating fires in the vicinity of ground mounted arrays include:

- Overgrown vegetative fuel may be under or around the array, or located in the vicinity of the array.
- Ground mounted structures may be used as shade structures for storage of equipment and/or supplies.
- Vehicles may be parked under PV car ports.
- Tables, trash cans, and other combustible storage could be located beneath shade structures.
- On wild land fires, firefighters working around arrays that are involved in the fire should wear PPE and SCBA.

6.4. SIZE-UP

Given the different characteristics of a ground mounted array, a thorough size up needs to be performed so the firefighters at the incident understand the specific challenges posed by the ground mounted installation such as:

- Many ground mounted arrays may have access restricted by security fencing.
- Access roads may not be suited for all weather conditions, not maintained, or may be nonexistent.
- The PV system may be in a fire hazard severity zone.
- In rural areas, there may not be any fire hydrants or any additional water supply.
- There could be a delay in locating the inverter or identifying other controls.

Ground mounted systems will vary widely in the design and details of the system; specifically equipment installations will vary from site to site. Disconnecting means are typically (but not always) provided to turn off the conductors connecting the array to the facility using the power. The disconnecting means is often mounted on the array structure or on a nearby backboard. At the building being served, there may also be a means to disconnect the power from the array.

The following is a partial list of typical system configurations you may encounter:

Large commercial arrays will have disconnects and inverters situated behind and protection by the PV array.

- The inverter and the ac and dc disconnect are at the array.
- The inverter and the dc disconnect are at the array. The ac disconnect is at the main service panel on the building being served.
- The dc disconnect is at the array. The inverter is at the building being served. The ac disconnect is at the main service panel on the building being served.
- The inverter is at the building being served. The dc disconnect is just upstream of the inverter and the ac disconnect is just downstream at the building being served.
- The inverter is at the building being served. The ac disconnect is at the main service panel on the building being served. The dc disconnect is just upstream of the inverter and at the array.

6.5. STRATEGY AND TACTICS

Following a good size-up of the incident, the choice of a strategic mode should be made by the IC following normal department SOP's. Tactics, like the strategy, should also be based upon normal standard operating procedures

6.5.1 Strategy

In addition to department policies, the following items must also be considered when developing a strategy:

- Fire conditions found on arrival.
- Is it the array that's burning or is a fire exposing the array?
- Threatened exposures including wild land areas
- Water and additional resources available

Once the IC has completed a size-up and developed an Incident Action Plan, the IC should determine the strategy and assign tasks to the fire companies. Due to the hazards associated with PV systems, the IC may need to adjust the strategy and potentially re-arrange the order of the tactics in order to deal specifically with the technology. If the IC chooses an offensive strategy it needs to be supported as any other fire operation with an emphasis on disabling all power sources to and from the PV system.

6.5.2 Tactics

Tactics will be based on the chosen strategy and department SOP's. If it is known that a PV System is present, utility control must become a primary objective. Isolation of the inverters and disconnecting the system from the main electrical panel will be an important task. The Utility Group should attempt to isolate all of the PV system by locating the system controls and opening all of the disconnect switches. The Utility Group must also look for and disable any other power source that can be connected to the system such as fuel, wind and hydro-electric powered generators.

Another priority will be preventing further extension of the fire and isolating it to its area of origin. If the PV system itself is on fire it must be assumed to be "Hot" during daylight. Fire suppression crews should avoid physical contact with PV system components until it can be confirmed by a qualified PV technician or electrician that all power sources have been isolated. It may take time for the technician to respond and locate all of the system controls.

or dry chemical extinguishers should be used to contain or extinguish electrical fires. Water should be used to extinguish any ordinary combustibles under or near the ground mounted PV system, or if the volume of fire requires it use. If water is used, a 30º fog pattern from at least a 30 foot distance, at 100 psi is recommended. Full PPE must be used due to the potential toxic inhalation hazard if panels are burning. Fire crews should position themselves upwind and out of any toxic atmosphere.

During the overhaul and mop-up phases of the firefight, firefighters should avoid all potential electrical hazards until there is confirmation that the system no longer poses an electric shock hazard. Firefighters must avoid inadvertently damaging PV components with their tools. The IC may need the assistance from local PV technician to assist with disabling the PV system and confirmation that all of the hazards have been mitigated before incident is terminated and the scene is turned over to the owner or responsible party.

This ground mount array is equipped with a battery back-up system and battery meter or battery charge controller.

SECTION 7: OFF-GRID SYSTEMS

Terminal Objective

At the conclusion of this module students will be able to recognize types of photovoltaic systems, components, hazards and related factors when systems are involved in emergency response and recognize and understand mitigation.

Enabling Objective

The student will be able to:

- Identify system components
- Identify hazards with PV systems
- Identify system locations

7.1 INTRODUCTION

Off- grid, or stand-alone systems are defined as photovoltaic systems which are not connected to the local electrical utility's supply grid. Off -grid systems generally produce electricity for use in close proximity to the PV array. While most off-grid systems use banks of batteries for the storage of electricity, some systems may not.

Off-grid systems are most often found in rural areas which are not well served by the electrical utility companies. Instead of the current produced being converted to alternating current, these systems may be used to directly power direct current (dc) lighting or motors. However, in most cases, the electricity produced during daylight hours will be "banked" in on-site batteries for later use. Once banked, the electricity may be used as dc or converted to alternating current (ac) by means of an inverter. Like grid-tied systems, off-grid systems may be located on a structure. However, in the rural setting, the systems may be ground, roof or pole mounted, or any combination thereof.

In addition to the hazards identified in grid-tied systems, off-grid systems have their own set of hazards that firefighters should be aware of. These include:

- Systems may have been installed without permits or inspection.
- Some components, such as charge controllers, may be "homemade".
- Systems may lack discernable controls.
- Systems may lack signage.
- System components may be ungrounded.
- Battery storage banks may be located within rooms not suited for that purpose.
- Battery storage banks may be located in adjacent or "out" buildings.

- Hydrogen gas, produced while charging the batteries, is flammable and can ignite or explode if allowed to collect in unvented spaces.
- Battery storage systems may have numerous exposed terminals and conductors.
- Batteries typically contain acid which may spill if the batteries are involved in a fire.
- Batteries may also receive charging current from other sources such as fuel powered generators and wind or water mills.

Indicators that a PV equipped structure is off-grid and may have battery storage sets include the lack of a "service drop" from adjacent power lines or the lack of a service panel and meter. The presence of a fuel, wind or hydro powered generator may also be an indication that the structure is off-grid. Firefighters arriving at an incident involving a PV system or fire involving a structure equipped with a PV system in rural areas should look for battery storage systems and alternative generating sources during their size-up.

As with any utility supplied electrical source, an effort should be made to disconnect, or shut off the electrical current. Disconnect switches for PV systems equipped with batteries can usually be located near the battery bank and on the conductor(s) leading away from the batteries.

If the current coming from the batteries is being converted to AC, the disconnect switches and inverter may be configured in a manner similar to grid-tied systems; a disconnect switch located on the battery side, immediately upstream of the inverter.

Batteries used in storage systems are typically deep cycle batteries and rated 6, 12 or 24 volts DC. While individually these batteries have high amperage ratings, they lack sufficient voltage to cause life threatening injuries. However, if the batteries are connected in "series", the voltage can easily be increased to dangerous levels. Firefighters should avoid cutting or disconnecting the jumper wires that connect batteries to each other or to the system because of the arcing that may occur. Firefighters should also be cautious when using metallic tools around batteries as contact with battery terminals could result in fusing of the tool to the terminal.

Whenever practical, dry chemical or CO_2 extinguishers should be used on fires involving electrical equipment. This recommendation holds true for fires involving PV battery systems as well. As previously stated, typical batteries used for PV storage systems are lead- acid. When batteries are involved in fire, the plastic case containing the acid will melt, spilling the strong acid solution and creating a hazardous materials problem.

Terminal Objective

At the conclusion of this module students will be able to recognize types of photovoltaic systems, components, hazards and related factors when systems are involved in emergency response and recognize and understand mitigation.

Enabling Objective

The student will be able to:

- Identify system components
- Identify hazards with PV systems
- Identify system locations

8.1 INTRODUCTION

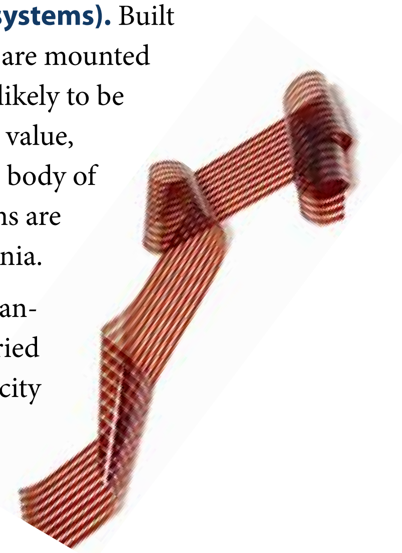
New products that convert solar energy to electricity are constantly under development. Some may be placed in service and some may go by the wayside. In the future, it is likely that firefighters may need to be familiar with a wide variety of solar technologies in addition to the photovoltaic systems that have been discussed in this training course. As with many evolving technologies, there will be some developments that will reach the market and some that won't. The following is a list of technologies currently being developed:

Curtain Walls/BIPV. New high rise buildings may incorporate PV modules into the curtain walls on the south and west sides of the building. These systems are already in use in some locations in the US, Asia, and Europe. Of concern to emergency responders is vertical fire spread across what would otherwise be a non-combustible surface. Additionally, some of the modules (thin film) incorporate 2 layers of non-tempered glass, which could result in an increased falling glass hazards on the fire ground.

Smart Modules (Module level control). Several products are either in development or commercially available. This technology could put a higher level of communications and control at each module. They are marketed for increased performance in shaded conditions and energy production. The benefit to firefighters is that technology allows them to shut down power at the "module level" in the event of an electrical short or fire. This technology could be used by emergency responders to provide module level shut off in the event of a fire.

Roof covering systems that are made entirely of PV. Similar to the BIPV modules, these PV modules would form the covering of the entire roof. There would be no roof covering or decking below the roof covering, just the membrane/insulation system. Currently these systems are in use in Asia and Europe. They are not yet available in the United States.

Float-o-voltaics (floating PV systems). Built on pontoons, these PV modules are mounted on a floating platform. They are likely to be found where there is a high land value, such as farm lands and there is a body of water nearby. At least two systems are currently in operation in California.



Power plastics. Flexible solar panels that can be rolled up and carried anywhere. It can generate electricity from indoor light or outdoor light. Can be configured as a window awning, outdoor canopy, or in consumer products (tents, umbrellas, handbags, clothing, etc.). Currently used by the military and on the market in a variety of forms.

Roof-top concentrating solar PV (CPV). This technology uses reflective metal troughs beneath a narrow row of PV cells in a "C" shape. The troughs focus the energy from the sun onto the PV cells to generate electricity. The troughs move throughout the day and focus the sun's energy to optimize power generation. A demonstration project is in place in California on a public building.

Solaren contracted with PG&E to bring solar energy from space.

Electricity from Space. In April 2009 Pacific Gas and Electric signed a contract with Solaren to procure up to 200 MW of electricity from the sun. Solaren plans to provide this electrical power to PG&E's customers from solar panels mounted on satellites placed in Earth's orbit. The satellite would convert this energy into radio waves and send it to a receiving station in Fresno County, California. The plan is to provide 200 megawatts of continuous power, estimated as the average usage of 150,000 homes. The schedule for completion is 2016.

Solar-paint. A group in the United Kingdom is currently developing a PV energy producing paint. The paint is dye-sensitized to generate electricity which is then transferred to a collection circuit. The paint is not expected to be as efficient as the types of solar modules you see today – but it may be less expensive. It would be in the form of a liquid paste. The paint is designed to be used on architectural steel but it may also have automotive applications. The developers hope to have this product in commercial production by 2014.

Full spectrum PV. Full spectrum PV is currently in development. The advantage to full spectrum PV systems is that the generate electricity of a much wider spectrum of light that the current systems but in particular, they can generate electricity on cloudy days. A disadvantage for firefighters is that lighting from ambient light sources, including scene lighting, will cause the PV modules to produce electricity.

Like Solar-paint, PV glitter, or Microphotovoltaics, has the potential for a wide range of applications such as incorporating the material into an entire roof covering system or fabrics like clothes and tents to recharge portable electronics.

Solar thermal systems are similar to PV in that they may occupy roof space. Typical solar thermal systems are used to heat water to either low temperatures (like for a swimming pool), medium temperatures (for domestic water heating; space heating; space cooling; or a combination of all three), or high temperatures (to produce steam for electric generation). Most solar thermal systems located on homes and businesses are for pool heating or domestic hot water.

Solar Thermal Applications

Below is brief summary of some of the typical solar thermal systems that are seen in California.

Solar Pool Heating. These systems primarily use flexible plastic panels. Panels are usually 4'x10' and have long, small tubes which convey water from the pool through the panels. As the water moves through the panel it gets warm. The solar pool heater typically uses the pool filtration pump to circulate water from the swimming pool through the solar panels, although sometimes there is a booster pump to help move the water through the panels at the correct velocity for heat collection. Individual panels are lightweight (less than 75 pounds). Multiple panels are connected together. Most systems will use enough panels to roughly equal one-half of the surface area of the swimming pool (a 20' by 30' swimming pool has a surface area of 600 square feet so a typical solar pool heating system would use about 300 square feet of solar panels). Plastic flexible panels can be cut through or easily removed for ventilation operations.

Solar Water Heating. Solar water heating is used to reduce the amount of energy needed to heat water for household uses (bathing, laundry, cleaning, and sanitation). In California, solar water heating systems can provide as much as 75% of the hot water needed for a typical single family home. Solar water heating is used in residential, commercial, and agricultural applications. Solar water heating systems come in many configurations:

Thermosyphon systems: an insulated storage tank is located above the solar panels allowing natural convection of heat (heat rises) to move the heated water into the storage tank.

Integral Collector Storage: an un-insulated tank which heats water and has no back-up storage.

Active systems: a system made up of one or more collectors and a storage tank. A pump is used to circulate heat transfer material through the collector back to the storage tank.

> Note: both thermosyphon and integral collector storage systems add significant weight to the roof which should be of concern to firefighters.

Active systems use a variety of heat transfer materials: potable water, food-grade propylene glycol, or air. Systems that do not use water will include a heat exchanger to transfer the energy collected to the potable water in the storage tank.

Single family solar water heating systems typically use about 40-60 square feet of solar panels and they weigh less than 5 lbs/sq. ft (similar to PV) if they are not thermosyphon or integral collector storage systems.

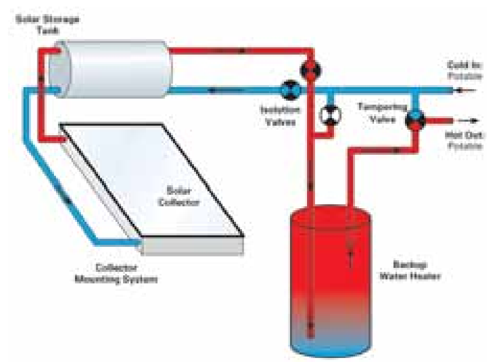
Space conditioning. Space conditioning systems will typically be active systems designed to provide heat in the winter or air conditioning in the summer. Most, if not all of these systems, will produce more energy than is needed so they will use the extra energy to provide domestic hot water. All of these systems are custom designed and may be hooked to a radiant floor system or a radiator system. Space conditioning systems will usually use more overall square footage of solar panels than a system designed just to provide domestic hot water.

Solar Thermal Components

Typical components of a solar thermal system include:

Collector(s). Solar thermal collectors come in several forms:

- A panel made up of risers attached to two manifolds. For low temperature applications (like pool heating) the panel is exposed to the elements. For low to medium temperature applications (domestic water heating and pool heating in cooler climates), the panel is placed in an insulated aluminum box with a glass cover.
- A trough with a focal point where energy is collected
- A plenum
- A low profile tank



Thermosyphon Systems: where the heated water rises naturally from collector to storage tank.

Storage. Storage for solar thermal systems usually look like a typical household water heater. Larger systems may have larger custom storage tanks.

Pump. Not all systems have pumps but many have small recirculation pumps that turn on based on the temperature differential between the collector and the storage tank.

Heat Exchanger. Not all systems have heat exchangers but many have them. Heat exchangers are located in the storage tank to transfer the energy collected from the solar panel and transfer it to the potable water in the storage tank.

Controller. A controller is used to monitor the temperature of the collector and the storage tank to control when the pump (if the system uses a pump). Low-voltage sensors are connected to the storage tank and the collectors.

Power block (for electric generation only). For systems that are used to generate electricity a power block will be attached to the solar thermal system to generate electricity. These systems are not currently seen anywhere except in utility scale applications.

Less Common Configurations

New solar thermal technologies are entering the market, in particular, combined solar thermal and PV systems. One approach to combine solar thermal and PV employs a plenum beneath the PV panel which is connected to a heat exchanger. Another approach is a system which uses focal mirrors to direct the sun's energy to one or more focal points (one for solar thermal and a second for PV).

Solar water heating can be found in conjunction with solar electric panels.

Author(s): Jesse Roman. Published on January 4, 2016.

Power to Spare

As energy storage systems revolutionize power management, enforcers and responders tackle a host of emerging safety questions. BY JESSE ROMAN

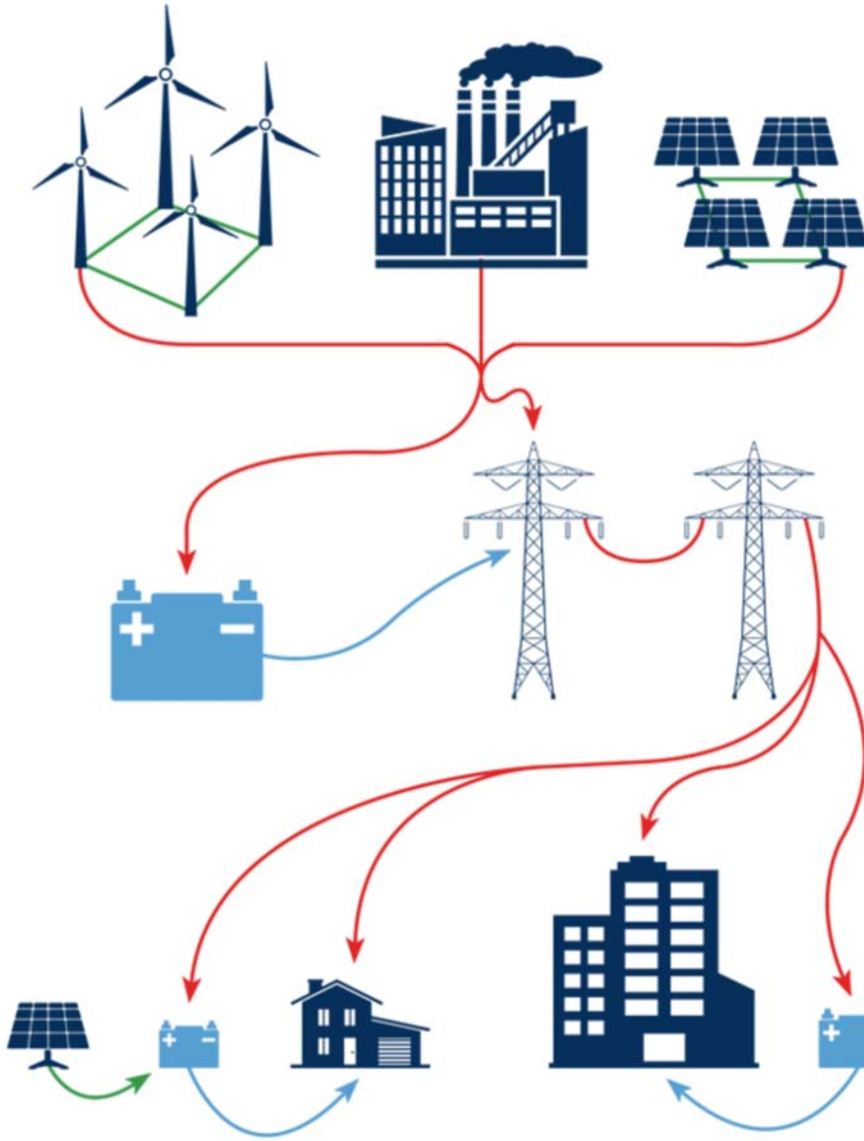
LAST APRIL, at his car company's design studio in Hawthorne, California, Tesla CEO Elon Musk strode onto the stage to announce the launch of a new initiative called Tesla Energy. The project's aim, he told an enthusiastic crowd, is nothing short of "a fundamental transformation of how the world works (and) how energy is delivered across Earth."

He then unveiled two rechargeable lithium-ion battery packs: the Powerwall, for residential use, and the Powerpack, designed for industrial use. The Powerwall, roughly the shape and size of a large boogie-board, is meant to hang on a wall in a garage or utility room, like a home appliance. The Powerpack, which resembles an oversized refrigerator, has already been installed at approximately 50 sites across the United States, Tesla says, and will soon be installed in at least two-dozen large office buildings in California, with more to come. Both batteries are based on technology that Tesla pioneered to power its Model-S vehicles, but instead of driving a wheel axle, the batteries are designed to store energy to power a home or office—or, if scaled up, a factory, airport, hospital, or even an entire electrical grid.

While Tesla Energy's splashy launch caught the attention of a broad audience, big batteries—or energy storage systems (ESS) in industry parlance—have been gaining momentum for more than a decade. Clean-energy government incentive programs, such as New York's Reforming the Energy Vision (REV) initiative and California's Self-Generation Incentive Program, are having the intended impact of driving more widespread adoption of energy-storage technology. In fact, many observers believe the world is on the cusp of an energy-storage bonanza. The market research firm IHS Technology predicts that, by 2017, the annual installation of energy storage worldwide will be six gigawatts (GW), enough to power 6 million homes. IHS forecasts that annual energy storage installations will exceed 40 GW by 2022, up from just 0.34 GW in 2012 and 2013 combined.

The allure of batteries goes well beyond environmental altruism. The ability to store energy for use later means consumers and businesses can buy electricity when prices are low and use it when demand on the electric grid causes power prices to sharply rise. The practice, called peak shaving, can potentially save large energy users hundreds of thousands of dollars per year. Hospitals, data centers, airports, and other facilities with critical operations can use battery power to ensure business continuity in a disaster. Energy storage also appeals to individual consumers; when combined with solar energy, the systems promise potential freedom from grid as well as backup power in an outage.

Energy storage is also fast becoming a critical resource for electric utility companies. Batteri allow utilities to have extra energy available to carry the electricity load during infrequent spil in demand, such as during a summer heat wave in New York City. Without energy storage, th utilities' only option to meet peak demand is more generation—turning on or building more power plants. It's an inefficient system that results in total generation capacity far exceeding demand the majority of the year. "In fact, 95 percent of the time, substations are underutilized," says Amaury De La Cruz, the demand management program director at ConEdison, one of the largest utilities in the United States. "But whenever there is an increase in peak demand, we need to invest in our system and build more wires and substations—energy storage allows us to defer that." Tesla's Musk has claimed that with properly deployed stationary storage, half of the world's power plants could shut down with no impact on the electrical grid.



Read more: The flow of energy. Illustration icons: Shutterstock

Tesla has already sold out of Powerwall and Powerpack batteries through 2016, taking orders worth more than $1 billion, Musk told reporters during an earnings report conference call. The company will ramp up production dramatically in 2017 when its $5 billion production facility, the Gigafactory, opens in the Nevada desert. "We believe we're at the start of a rapidly growing deployment of these systems," Scott Kohn, Tesla's senior manager of battery safety and research and development, told me at a meeting at the company's Palo Alto headquarters in the fall. "This is only the very beginning."

While the case for energy storage is obvious, what's less clear is what happens when something goes wrong. How do batteries of various chemistries and technologies react in a fire? How do firefighters make sure burning batteries are fully extinguished? How do responders handle a damaged battery that still contains energy? What are the risks to first responders and the public from exposure to toxic fumes, electricity, and other hazards associated with ESS if a fire or other incident were to occur? As an industry with vast potential to change the world gains prominence, public safety officials are scrambling to find answers.

Recognizing gaps

Two years ago, Lt. Paul Rogers, a hazardous materials expert with the Fire Department of New York (FDNY), was asked by his chief to attend a meeting on energy storage at FDNY headquarters in Brooklyn. He knew nothing about batteries before the meeting, but the information he came out with made him anxious.

To promote clean energy and solve an electricity supply crunch, New York State and the electric utility ConEdison were planning to incentivize customers in New York City to install ESS in their buildings. It likely meant that owners of buildings and businesses would soon seek to install various types of big batteries everywhere—high-rise buildings, homes, urban neighborhoods, business parks, substations, and all manner of spaces and occupancies in between. “I started thinking that the fire service really had no procedures for any of this stuff,” Rogers said. “I realized we had some major gaps.” Rogers has since become one of the country’s leading fire service experts on ESS, almost single-handedly pushing FDNY and the fire service forward on the issue.

Read more: New York City emerges as an epicenter of the energy storage revolution. Photograph: Shutterstock

Several months after that meeting, Rogers began talking to NFPA about the research and standards that existed to help FDNY vet the barrage of ESS applications the city expected to receive. Aside from some baseline information in NFPA 1, Fire Code, and NFPA 70®, National Electrical Code®, there wasn’t much.

As a result of those discussions, NFPA, the Fire Protection Research Foundation (FPRF), and FDNY partnered to host an ESS safety workshop in November at FDNY’s training facility on Randall’s Island. The event brought together about 60 leading professionals from government, the insurance industry, the fire service, utilities, the ESS industry, the codes and standards world, and others to discuss the current state of ESS, as well as gaps in safety knowledge, codes and standards considerations, and research needs. “We needed some sort of tangible takeaway—we were adamant about that," Rogers told me of the decision to hold the workshop. "I thought we captured some really good information."

A report will be generated from the proceedings to help New York and other communities better evaluate ESS installation applications. The report will also inform codes and standards development, research, ESS design, and product testing. The proceedings are available on the FPRF's website, nfpa.org/foundation.

Work on ESS is happening elsewhere, too. In December, 2014, the U.S. Department of Energy (DOE) published its "Energy Storage Strategic Plan," which identifies three key needs: standardized methods to validate system safety; updated codes, standards, and regulations for ESS safety; and procedures to safely respond and handle ESS emergencies and incidents. NFPA, Underwriters Laboratories (UL), the FPRF, and several other entities are all working to address those gaps.

At least two outside groups have indicated that they intend to submit a request for NFPA to develop a new ESS standard to help first responders, manufacturers, and installers better understand and mitigate potential ESS hazards. Such a document would likely address installation, siting, testing, maintenance, ventilation, and fire protection, among other things, said Rich Bielen, NFPA's manager of Fire Protection Systems Engineering. If NFPA's Standards Council green-lights the project, it would likely take about three years for the first edition to emerge, Bielen said.

One approach could be to create an entirely new standard; another could be to update existi codes and standards to include more on ESS—such as adding ESS suppression guidance to NFPA's suppression documents—and then creating a standard that pulls all of the informatic together. That effort is underway now in NFPA 1. An extensive overhaul of Chapter 52 of the code is being explored to provide more detail on the various battery chemistries used in ESS and to establish the protection measures that go with those technologies. Some of the work will involve collecting existing information, while much of it requires new research and a lot more discussion.

Dynamic technology

Developing protocols for evaluating ESS systems and creating emergency procedures is a complex task, in part because the target keeps moving—ESS technology is constantly expanding and evolving. The roots of ESS go back to the 1930s and pumped-hydroelectric storage, a mechanical form of energy storage that has played a significant role in the reliability of the electric grid. The concept is simple: during periods of high electric demand, a large reservoir of water is drained into a lower reservoir, turning a turbine in the same manner as a conventional hydropower station. Pumped hydro still accounts for 95 percent of the world's installed stored energy capacity, but that's changing. Increasing needs for more flexible and reliable energy supplies, the growth in renewable energy, more stringent environmental regulation, and recent technological advances have all paved the way for the rapid rise in electro-chemical energy storage in the form of big batteries.

In 2003, the Golden Valley Electric Association, an electric utility near Fairbanks, Alaska, undertook one of the largest ESS battery projects to date, installing a 1,500-ton nickel-cadmium battery to provide backup power to its 44,000 customers. The battery, still one of the world's most powerful, can provide as much as 27 megawatts (MW) of power for 15 minutes—enough time for utility crews to start up local generation in case there is an issue with the power supply from primary power plants further away. In 2014 the battery responded to 78 events, preventing a total of 263,489 customer outages, according to Golden Valley.

More recent technological breakthroughs have reduced costs and allowed energy storage to also become viable for businesses and individual homeowners. In 2010, the California Public Utilities Commission awarded $1.8 million to SolarCity, a residential photovoltaic panel installer, to study the feasibility of using batteries to store the electricity generated by rooftop solar arrays. "As soon as distributed solar starts providing 5 to 10 percent of demand, its intermittent nature will need to be addressed," Peter Rive, SolarCity's co-founder and chief operating officer, said at the time. "We think in the years ahead this will be the default way that solar is installed."

"If your goal is to build a meaningful solar business that is durable over time, you have to assume that that solar business is going to morph into a solar-plus-storage solution," Steve McBee, chief executive of NRG Home, one of the largest independent power producers in the U.S., said recently. "That will be mandatory at some point."

That future is already emerging.

More industries are turning to energy storage either to complement their wind and solar panel systems or to cut their electricity bills by peak shaving. The U.S. Department of Energy's Glol Energy Storage Database currently lists nearly 1,400 commercial ESS projects now deployed around the world in a variety of settings and applications. Those include an advanced lead a battery storage system at Ford Motor's manufacturing plant in Dearborn, Michigan; thermal i energy storage at the Toronto Zoo; sodium-sulfur battery storage at a wind farm in Japan; flo batteries on the 25th floor of the Metropolitan Transit Authority headquarters in Manhattan; a a fleet of 24 hybrid-electric office buildings in California using 10 MW of lithium-ion energy storage. In New York City alone, ESS projects of at least five different battery chemistry types have been approved in both indoor and outdoor locations.

"Batteries are being installed more and more where people work, play, and sleep," said Roger Lin, the director of product marketing at the Massachusetts-based NEC Energy Solutions, which has installed battery systems around the globe. "There is a layered approach to safety that needs to be taken by everybody in the industry. If we are not doing this the right way, it will slow down adoption, but we have to do so without impacting reliability. There is a balance, and we have to figure out what it is."

Getting ESS right

The specific combination of hazards inherent in ESS is somewhat unique, but the individual threats—arc flash, fire, combustion, voltage, and toxicity—"are all hazards that already exist in places like New York City, and are associated with systems first responders are comfortable with, such as substations and chemical storage," said David Rosewater, an engineer at Sandia National Laboratories, who studies ESS.

For first responders, however, perhaps a bigger concern than the ESS itself is the migration of the systems into homes, offices, and factories. "If you respond to an ESS at a power plant, you understand that going in and you know to be cautious—it has typically been a hands-off approach," said Ken Willette, a former fire chief and the division manager for Public Fire at NFPA. "But when you put ESS into homes and occupied buildings, there is a different risk analysis—you may need to interact with it to contain a fire or make a rescue. Responders are asking, 'What do I need to know to make that risk analysis?' It's about understanding how the system works at a basic level."

If NFPA's ESS workshop in New York was any indication, stakeholders agree when it comes to the importance of getting ESS right, along with its related safety issues—a single event can give an emerging technology a black eye that's tough to recover from.

In 1973, for example, an explosion inside a 600,000-barrel liquid natural gas (LNG) tank on Staten Island lifted off the facility's concrete roof, which fell and crushed 40 people below. The tragedy left many questioning the safety of transporting and storing LNG near urban areas. Soon after, the state outlawed the construction of new LNG facilities, a ban that lasted more than 40 years. In January, 2015, New York's state Department of Environmental Conservation announced it was lifting the ban—but not in New York City. "The moral of that story is to work with us so we understand what the risks are," Rogers said to the ESS workshop participants, "and we will work with you to make sure everyone goes home safe and the occupants stay safe."

Read more: Ignition and reignition issues with the batteries in electric vehicles are also concerns for energy storage systems. Photograph: National Highway Traffic Safety Administration

Codes and standards developers and researchers are trying to do their part to prevent a similar incident involving ESS. In addition to NFPA's work on a potential new standard, in September NFPA received a $762,000 Assistance to Firefighters grant from FEMA that will be used to develop a trainer safety course on ESS, as well as a free interactive web-based course on ESS safety awareness for first responders. The initiative will involve working with FPRF, clean energy consulting firm Strategen, and other research groups to further develop ESS best practices for first responders. The web course is expected to be available at evsafetytraining.org and nfpa.org by late summer.

Meanwhile, UL is in the final stages of completing a new standard, UL 9540, which covers ESS safety testing. The new standard references a number of existing UL standards, including UL 1973, which addresses the safety of lithium-ion battery ESS. UL 9540 is expected to be finalized in early 2016, but product testing and certification to the draft standard have already begun. “These listings by UL ensure an even playing field, that there be a minimum level of safety out there,” said Rosewater, who was on the committee that developed the standard.

Research also continues to fill in some of the knowledge gaps. The FPRF will soon release a report that provides an overview of the ESS technology now being deployed and a hazard assessment for each. Part of that project involved partnering with Tesla recently on full-scale burns of Powerpacks in the Nevada desert. Testing explored both external and internal fire attack scenarios and involved measurement of temperatures, heat release rates, and vent gas composition.

Experts say storage will become an integral part of alternative energy generation such as wind and solar.
Photograph: Invenergy

Additionally, ConEdison has partnered with FDNY on small-scale battery-cell burn tests. The tests will address six different ESS technologies and measure several key variables: the heat release rate; what harmful gasses and liquids may come off of and out of the batteries during a fire; which suppression agents are effective in suppressing or extinguishing a battery fire; and if the fires produce any arcing, thermal runaway, or other events, and under what conditions. The tests will be used to create a computer model that can predict what would happen in full-sized fires. The final report is expected to be finished and publically available by late spring.

Even as progress occurs, many safety experts believe that there is still a long way to go to fully understanding adequate ESS protection and response. At NFPA's ESS workshop in New York, attendees split into breakout groups to consider safety topics for facility and building design, ESS and built-in fire protection systems, and emergency response tactics and strategies. The roughly 20 participants in the emergency response group included FDNY chiefs, ESS manufacturers, NFPA staff, ConEdison representatives, insurers, and others. The discussion was enthusiastic and productive, and also demonstrated the complexities of this sprawling issue. Topics ranged from electrocution risks of water from sprinklers pooling on the floor around an ESS system, to whether fire departments should require owners to disclose that they have ESS in their homes or businesses. At least one participant advocated for a national ESS tracking system. The issue of lithium-ion batteries igniting after being damaged, or reigniting after a fire has been extinguished, was raised. There was discussion on what kind of signs or markings should be required on the systems to alert first responders of the dangers associated with ESS. A remote shut-off switch should be a requirement, others said. And there were many questions. What about ventilation of potentially toxic gasses in an enclosed space—where should they go? What about system overhaul after a fire incident?

"The fire service is missing data and information about how these things react in a fire, but we're getting there," Rogers said. "The fire service is not opposed to any new technology—we just want to know what we are up against so we can manage the risks. Once we figure it out, we'll make it work. We always do."

JESSE ROMAN is staff writer for NFPA Journal. He can be contacted at jroman@nfpa.org.

Top Photograph: Jan Woitas/dpa/Corbis

Hazard Assessment of Lithium Ion Battery Energy Storage Systems

FINAL REPORT

PREPARED BY:

Andrew F. Blum, P.E., CFEI
R. Thomas Long Jr., P.E., CFEI
Exponent, Inc.
17000 Science Drive, Suite 200
Bowie, MD 20715

RESEARCH FOUNDATION

RESEARCH FOR THE NFPA MISSION

FIRE PROTECTION RESEARCH FOUNDATION
ONE BATTERYMARCH PARK | QUINCY, MASSACHUSETTS, USA 02169-7471
E-MAIL: FOUNDATION@NFPA.ORG | WEB: WWW.NFPA.ORG/FOUNDATION

FOREWORD

In recent years, there has been a marked increase in the deployment of lithium ion batteries in energy storage systems (ESS). Many ESS are being deployed in urban areas both in high rise structures and single- and multi-family residences. Local Authorities Having Jurisdiction (AHJs) along with the ESS integrators and installers are challenged by the lack of clear direction on fire protection and suppression in these installations. Without a recognized hazard assessment made available to standards developers, AHJs, emergency responders, and industry, guidance on safe installation of these systems will lack a technical basis.

The purpose of this project is to develop a hazard assessment of the usage of lithium ion batteries in ESS to allow for the development of safe installation requirements and appropriate emergency response tactics.

The Fire Protection Research Foundation expresses gratitude to the report author Andew Blum and Tom Long, who are with Exponent, Inc. located in Bowie, Maryland. The Research Foundation appreciates the guidance provided by the Project Technical Panelists, the funding provided by the project sponsors, and all others that contributed to this research effort. Thanks are also expressed to the National Fire Protection Association (NFPA) for providing the project funding through the NFPA Annual Code Fund.

About the Fire Protection Research Foundation

The Fire Protection Research Foundation plans, manages, and communicates research on a broad range of fire safety issues in collaboration with scientists and laboratories around the world. The Foundation is an affiliate of NFPA.

About the National Fire Protection Association (NFPA)

Founded in 1896, NFPA is a global, nonprofit organization devoted to eliminating death, injury, property and economic loss due to fire, electrical and related hazards. The association delivers information and knowledge through more than 300 consensus codes and standards, research, training, education, outreach and advocacy; and by partnering with others who share an interest in furthering the NFPA mission.

All NFPA codes and standards can be viewed online for free.

NFPA's membership totals more than 65,000 individuals around the world.

Keywords: energy storage systems, lithium ion batteries, fire hazard assessment, stranded energy

PROJECT TECHNICAL PANEL

Paul Rogers, FDNY HazMat

Benjamin Ditch, FM Global

Manish Mohanpukar, Idaho National Laboratory

Ken Willette, NFPA Public Fire Protection Division Manager

Daniel Gorham, NFPA 850 Staff Liaison

Mark Earley, NFPA 70 Staff Liaison

Randy Fish, California Energy Storage Alliance

Roger Lin, NEC Energy Solutions

Steven Sawyer, International Fire Marshals Association

Mark Boone, Dominion Resources Services Inc.

Celina Mikolajczak, Tesla Motors

Robby Dawson, Chesterfield County Fire & EMS

Leo Subbarao, FDNY Technology Management

Tamara Saakian, FDNY Technology Management

Andrew Klock, NFPA

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Fire Hazard Assessment of Lithium Ion Battery Energy Storage Systems

Fire Hazard Assessment of Lithium Ion Battery Energy Storage Systems

Prepared for

Fire Protection Research Foundation
One Batterymarch Park
Quincy, MA 02169

Prepared by

Andrew F. Blum, P.E., CFEI
R. Thomas Long Jr., P.E., CFEI
Exponent, Inc.
17000 Science Drive, Suite 200
Bowie, MD 20715

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Acronyms and Abbreviations

Ah	ampere hours
AHJ	authority having jurisdiction
APS	Arizona Public Service Company
BATSO	Battery Safety Organization
BMS	battery management system
CH_4	methane
Cl_2	chlorine
CO	carbon monoxide
CO_2	carbon dioxide
DC	direct current
DOE	Department of Energy
DOT	Department of Transportation
EDV	electric drive vehicle
EES	electrical energy storage
ELC	equivalent lithium content
ESS	energy storage system
FMEA	Failure Modes and Effects Analysis
FPRF	Fire Protection Research Foundation
ft	feet
g	grams
HCl	hydrogen chloride
HCN	hydrogen cyanide
HECO	Hawaiian Electric Company
HF	hydrogen fluoride
HFD	Honolulu Fire Department
HFG	heat flux gauge
HRR	heat release rate
IBC	International Building Code

ICC	International Code Council
ICE	internal combustion engine
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IFC	International Fire Code
in	inch
IRC	International Residential Code
JSA	Japanese Standards Association
kg	kilograms
kWh	kilowatt hours
LER	light electric rail
Li-ion	lithium ion
lpm	liters per minute
mph	miles per hour
MW	megawatt
NEC	NFPA 70, *National Electrical Code*
NEMA	National Electrical Manufacturers Association
NFIRS	National Fire Incident Reporting System
NFPA	National Fire Protection Association
NiCad	nickel cadmium
NO_x	nitrogen oxides
OSHA	Occupational Safety and Health Administration
PF_5	phosphorus pentafluoride
POF_3	phosphoryl fluoride
ppm	parts per million
psi	pounds per square inch
PVES	photovoltaic energy systems
SAE	Society of Automotive Engineers
SCBA	self-contained breathing apparatus
SDS	safety data sheet
SOC	state of charge

TC	thermocouple
UN	United Nations
UL	Underwriters Laboratories
UPS	uninterrupted power supplies
VOC	volatile organic compound
Wh	watt hours

Limitations

At the request of the Fire Protection Research Foundation (FPRF), Exponent performed a fire hazard assessment of lithium ion (Li-ion) batteries used in energy storage systems (ESSs). This report summarizes a literature review and gap analysis related to Li-ion battery ESSs, as well as full-scale fire testing of 100 kilowatt hour (kWh) Li-ion battery ESSs. The scope of services performed during this literature review and testing program may not adequately address the needs of other users of this report, and any re-use of this report or the findings, conclusions, or recommendations presented herein are at the sole risk of the user.

The full-scale Li-ion battery ESS test strategy, ignition protocols, and any recommendations made are strictly limited to the test conditions included and detailed in this report. The combined effects (including, but not limited to) of different battery types, ESS types, ESS size/battery capacity, internal or external ESS/battery damage, battery energy density and design, state of charge, and cell chemistry are yet to be fully understood and may not be inferred from these test results alone.

The findings formulated in this review are based on observations and information available at the time of writing. The findings presented herein are made to a reasonable degree of scientific and engineering certainty. If new data becomes available or there are perceived omissions or misstatements in this report, we ask that they be brought to our attention as soon as possible so that we have the opportunity to fully address them.

Executive Summary

In an effort to provide guidance to standards developers, authorities having jurisdiction (AHJs), emergency responders, and the energy storage system (ESS) industry, Exponent, in conjunction with FPRF, the Project Technical Panel, and industry sponsors, performed a fire hazard assessment of Li-ion battery ESSs. Currently, these entities do not have a clear direction regarding the fire hazards of ESS installations and have few, if any, technical studies, reports, or scientific literature to rely upon when making decisions regarding the safe installation of these systems. This report summarizes a literature review and gap analysis related to Li-ion battery ESSs, as well as full-scale fire testing of a100 kWh Li-ion battery ESS.

The scope of work included, but was not limited to, the following four primary tasks:

1. A literature review and gap analysis related to Li-ion battery ESSs;
2. Development of a detailed full-scale fire testing plan to perform an assessment of Li-ion battery ESS fire hazards;
3. Witnessing the implementation of the fire test plan through full-scale fire testing; and
4. A report of final results and a fire hazard assessment.

The overall project research objective was to develop a technical basis through a fire hazard assessment of Li-ion battery ESSs. This project is the first phase of an overall initiative with the goal to develop safe installation practices, fire protection guidance, and appropriate emergency response tactics for Li-ion battery ESSs based on the literature review and full-scale test results, as applicable. This project did not include an analysis or testing of fire detection systems, fire suppression systems, or emergency response tactics related to Li-ion battery ESS fire scenarios. A full listing of project observations/key findings as they relate to ESS fire hazards is provided in Section 7 of this report.

1 Background

1.1 Project History

Energy storage is emerging as an integral component of a resilient and efficient electrical grid through a diverse array of potential applications. It is anticipated that the evolution of the electrical grid will result in a greater need for services best provided by energy storage systems (ESSs). It is expected that the increase in demand for these systems will further drive energy storage research to produce systems with greater efficiency at a lower cost, which will lead to an influx of energy storage deployment across the country. To enable the success of these deployments, the hazards of these systems, namely the fire hazard of the ESS, must be understood.[1]

In recent years, there has been a marked increase in the deployment of lithium ion (Li-ion) batteries in ESSs. Many ESSs are being deployed in both high-rise structures and single- and multi-family residences. Local authorities having jurisdiction (AHJs) along with ESS integrators and installers do not have a clear direction regarding the fire hazards of these installations. A recognized fire hazard assessment available to standards developers, AHJs, emergency responders, and industry will provide guidance with a technical basis on the evaluation and safe installation of these systems.

1.2 Research Objectives and Project Scope

The overall project research objective was to develop a technical basis through a fire hazard assessment of Li-ion ESSs. This project is part of an overall initiative with the goal to develop safe installation practices, fire protection guidance, and appropriate emergency response tactics for ESSs. This project did not include an analysis or testing of fire detection systems, fire suppression systems, or emergency response tactics related to Li-ion battery ESS fire scenarios.

[1] Energy Storage Safety Strategic Plan, U.S. Department of Energy, December 2014.

The scope of work included, but was not limited to, the following four primary tasks:

1. A literature review and gap analysis related to Li-ion battery ESSs;
2. Development of a detailed full-scale fire testing plan to perform an assessment of Li-ion battery ESS fire hazards;
3. Witnessing the implementation of the fire test plan through full-scale fire testing; and
4. A report of final results and a fire hazard assessment.

A more detailed description of the tasks Exponent performed to fulfill the project objectives is provided below.

1.2.1 Literature Review and Gap Analysis

Exponent collected, reviewed, and summarized available literature related to Li-ion battery ESSs, including the Department of Energy (DOE) Safety Roadmap, relevant codes and standards, incident reports, related test plans, and previous fire testing/research. The literature review also identified existing gaps in the information currently available and the practices utilized in the deployment of Li-ion ESSs, if any.

1.2.2 Fire Test Plan

Exponent, in conjunction with the Project Technical Panel, developed a detailed test plan to provide an assessment of fire hazards posed by Li-ion ESSs. Li-ion ESSs with an approximate capacity of 100 kilowatt hours (kWh) designed for use in commercial applications were tested.

1.2.3 Witness of Fire Testing

Exponent witnessed the full-scale fire testing at the manufacturer's testing site and summarized the test observations and data provided to Exponent.

1.2.4 Final Report

Exponent collected and summarized the results of the above tasks in a formal research engineering report, including:

1. An overview of the project work to date;
2. A summary of the full-scale fire tests;
3. A fire hazard assessment; and
4. Identification of future potential research.

2 Literature Review and Gap Analysis

Exponent collected, reviewed, and summarized available literature related to ESSs and Li-ion batteries. The literature review provides an overview of energy storage (Section 2.1), commercial and residential ESSs (Section 2.2), a brief summary of Li-ion technology (Section 2.3), codes and standards related to ESSs (Section 2.4), fire incidents involving ESSs (Section 2.5), large format Li-ion battery fires (Section 2.6), and a gap analysis (Section 2.7).

2.1 Energy Storage Overview

An ESS provides a means to store energy for later use to supply the utility grid or local grids.[2] An ESS may utilize any of the following technologies:

1. **Electrochemical.** Consists of a secondary battery, electrochemical capacitor, flow battery, or hybrid battery-capacitor system that stores energy and any associated controls or devices that can provide electric energy upon demand.

2. **Chemical.** Consists of hydrogen supply equipment or other fuel supply equipment combined with a fuel cell power system or generator to convert the fuel to electrical energy.

3. **Mechanical.** Consists of a mechanical means to store energy, such as through compressed air, pumped water, or fly wheel technologies and associated controls and systems, which can be used to run an electric generator to provide electric energy upon demand.

4. **Thermal.** Consists of a system that uses heated fluids, such as air, as a means to store energy along with associated controls and systems, which can be used to run an electric generator to provide electrical energy upon demand.

This report focuses on Li-ion battery ESSs for commercial and residential installations, which are an electrochemical technology.

[2] UL 9540, *Outline of Investigation for Energy Storage Systems and Equipment*, Issue Number 1, June 30, 2014.

An ESS allows for the balance of supply and demand of electrical energy, utilizing stored energy during "peak demand" times and storing energy during times of "low demand." An example of a common ESS is pumped-storage hydroelectricity (pumped hydro). Pumped hydro stores large quantities of water in elevated reservoirs by utilizing excess electricity at times of low demand to pump water into the reservoirs. The facilities then release the water, which passes through turbine generators and converts the stored potential energy to electricity when electrical demand peaks.[3]

Recently, a more common solution is the storage of energy in a battery. Batteries have historically been of limited use in large scale electric power systems due to their relatively small capacity and high cost. However, newer battery technologies have been developed that can provide significant utility scale capabilities.[4] In addition to utility scale applications, smaller commercial and residential ESSs utilizing batteries are also becoming more prevalent.

2.2 Commercial and Residential ESS Overview

The most common commercial and residential ESSs are electrochemical systems utilizing batteries. Currently, there are many different battery chemistries (e.g., lead acid, sodium sulfur, lithium iron phosphate, Li-ion) utilized in ESSs deployed in North America; however, Li-ion is the most popular[5] and will likely continue to grow in popularity with the planned release of new ESS products in the coming years.

Residential ESSs are typically sized between 1 and 10 kWh[6,7,8] and standalone commercial systems can be much larger (20 to 100 kWh), modular, and interconnected to produce even greater capacity. The systems can vary in voltage depending on the design of the batteries, the ESS power management systems, and the manufacturer. Current products installed in the market have voltages as low as 48 volts and as high as 1000 volts DC. ESSs typically work by

[3] Wald, Matthew, L. Wind Drives Growing Use of Batteries, *The New York Times*, July 27, 2010.

[4] Wald, Matthew, L. Wind Drives Growing Use of Batteries, *The New York Times*, July 27, 2010.

[5] Energy Storage Safety Strategic Plan, U.S. Department of Energy, December 2014.

[6] http://www.samsungsdi.com/ess/overview

[7] http://www.teslamotors.com/powerwall

[8] http://www.aquionenergy.com/energy-storage-battery

storing power collected from the grid, a solar installation, wind installation, or other source during a low demand time (typically during the day) and then using the stored energy during peak hours (typically in the mornings and evenings), as illustrated in Figure 1.[9,10]

The ESS typically consists of the batteries, a mounting frame or shelf for the batteries, a cooling system (i.e., fan, radiator, and hoses), power electronics, and an enclosure (the outer cover or cabinet) that these components are stored within. A residential ESS can be installed inside a residence or building, typically within the garage or attic, or installed on the exterior of the structure. A commercial ESS can be installed outside along a property line, next to a building, or inside a shipping container.

Pumped hydro remains one of the oldest and most mature energy storage technologies, having been utilized safely since the 1800s. Its hazards are well known and defined. Battery ESSs, however, are much earlier in their development and deployment cycle and, given recent trends, have not reached the full extent of their deployed capacity.[11] The hazards associated with these systems are not well known and are less defined than other traditional ESS technologies, such as pumped hydro. When discussing ESSs in the remainder of the report, Exponent is referring to Li-ion battery ESSs for use in commercial applications.

[9] http://www.samsungsdi.com/ess/overview

[10] http://www.teslamotors.com/powerwall

[11] Energy Storage Safety Strategic Plan, U.S. Department of Energy, December 2014.

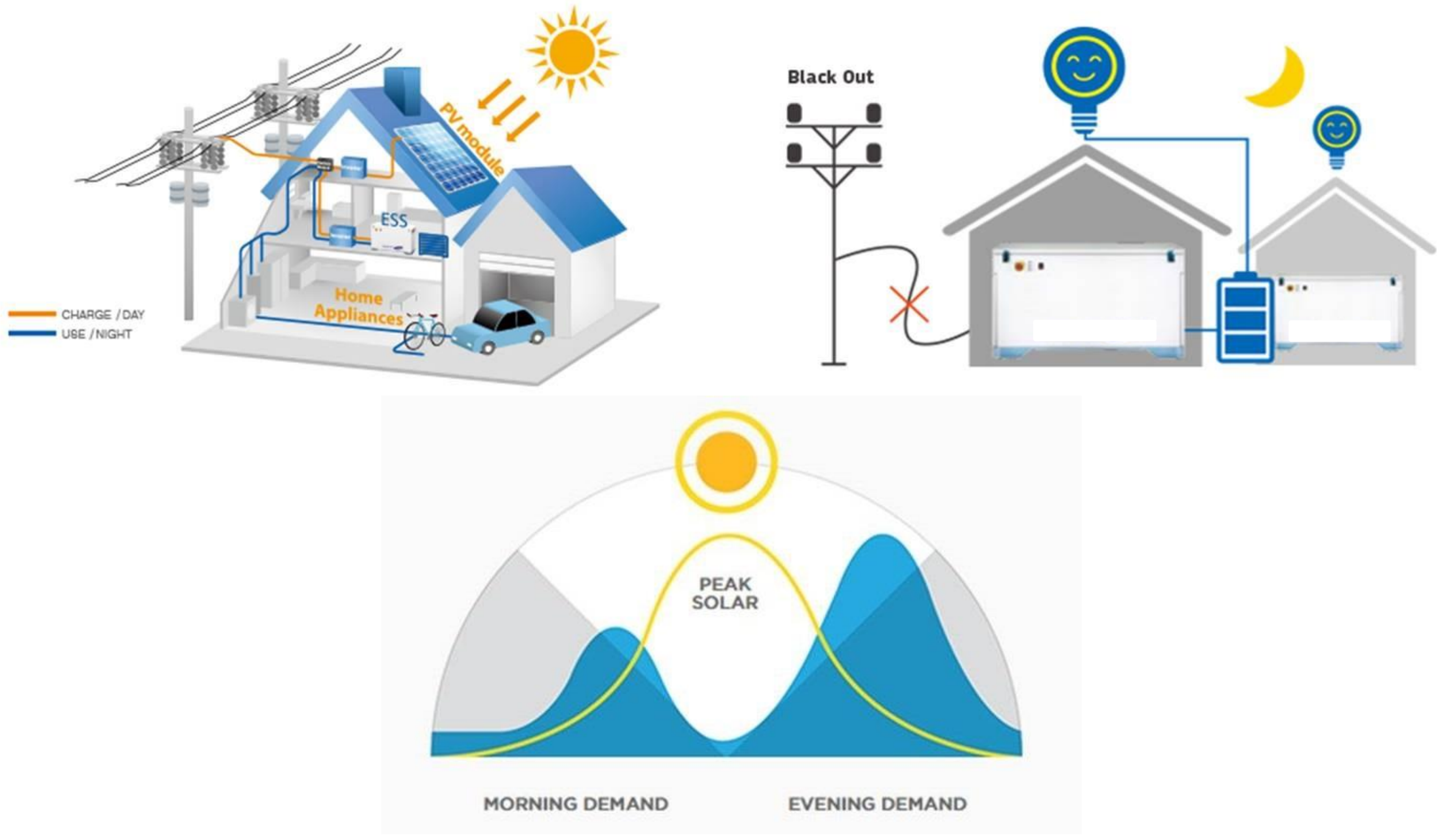

Figure 1 Illustration of energy storage during off peak hours (top left); use of energy storage during peak hours or power interruptions (top right); and the typical energy consumption curve (bottom)[12]

[12] http://www.samsungsdi.com/ess/residential-commercial-solution

2.3 Li-ion Battery Overview

Li-ion battery cells are in wide consumer use today. As this technology has evolved and the energy densities have increased, the use of this technology has been applied across many consumer products, including the energy storage industry. Li-ion battery cells arranged in large format Li-ion battery packs are being used to power ESSs. As ESSs enter the United States consumer marketplace, there is an expectation of a steep increase in the number and size of battery packs in storage and use. Recent studies by the National Fire Protection Association (NFPA) Fire Protection Research Foundation (FPRF)[13,14,15,16] highlight the potential hazards of Li-ion battery cells and large format packs during the life cycle of storage, distribution, and use in products. An overview of the Li-ion technology and its failure modes is also included. A brief summary of Li-ion technology is provided here.

Li-ion has become the dominant rechargeable battery chemistry for consumer electronic devices and is poised to become commonplace for industrial, transportation, and energy storage applications. This chemistry is different from previously popular rechargeable battery chemistries (e.g., nickel metal hydride, nickel cadmium, and lead acid) in a number of ways. From a technological standpoint, because of high energy density, Li-ion technology is an effective battery type to use in ESSs. From a safety and fire protection standpoint, a high energy density coupled with a flammable organic, rather than aqueous, electrolyte has created a number of new challenges with regard to the design of batteries containing Li-ion cells, and with regard to fire suppression.

[13] Mikolajczak, C., Kahn, M., White, K., and Long, RT. “Lithium-Ion Batteries Hazard and Use Assessment.” Fire Protection Research Foundation Report, July 2011.

[14] Long RT and Mikolajczak CJ. “Lithium-ion batteries hazards: What you need to know.” Fire Protection Engineering Q4 2012.

[15] Long RT, Blum AF, Bress TJ, and Cotts BRT. “Emergency response to incidents involving electric vehicle battery hazards.” Fire Protection Research Foundation Report, July 2013.

[16] Long RT, Sutula JA, and Kahn MJ. “Lithium-ion batteries hazard and use assessment Phase IIb.” Fire Protection Research Foundation Report, 2013.

2.3.1 Anatomy of a Li-ion Cell

The term "Li-ion" refers to an entire family of battery chemistries. It is beyond the scope of this report to describe all of the chemistries used in commercial Li-ion batteries. In addition, Li-ion battery chemistry is an active area of research and new materials are constantly being developed. Additional detailed information with regard to Li-ion batteries is available in a number of references[17,18] and a large volume of research publications and conference proceedings on the subject.

In the most basic sense, the term "Li-ion battery" refers to a battery where the negative electrode (anode) and positive electrode (cathode) materials serve as a host for the lithium ion (Li+). Lithium ions move from the anode to the cathode during discharge and are intercalated (inserted into voids) in the crystallographic structure of the cathode. The ions reverse direction during charging, as shown in Figure 2. Since lithium ions are intercalated into host materials during charge or discharge, there is no free lithium metal within a Li-ion cell,[19,20] thus, if a cell ignites due to external flame impingement or an internal fault, metal fire suppression techniques are not appropriate for controlling the fire.

In a Li-ion cell, alternating layers of anodes and cathodes are separated by a porous film (separator). An electrolyte composed of an organic solvent and dissolved lithium salt provides the media for Li-ion transport. A cell can be constructed by stacking alternating layers of electrodes (typical for high-rate capability prismatic cells), or by winding long strips of electrodes into a "jelly roll" configuration typical for cylindrical cells, as shown in Figure 3. Electrode stacks or rolls can be inserted into hard cases that are sealed with gaskets (most commercial cylindrical cells), laser-welded hard cases, or enclosed in foil pouches with heat-

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[17] *Linden's Handbook of Batteries*, 4th Edition, Thomas B. Reddy (ed), McGraw Hill, NY, 2011.

[18] *Advances in Lithium-Ion Batteries*, WA van Schalkwijk and B Scrosati (eds), Kluwer Academic/Plenum Publishers, NY, 2002.

[19] Under certain abuse conditions, lithium metal in very small quantities can plate onto anode surfaces. However, this should not have any appreciable effect on the fire behavior of the cell.

[20] There has been some discussion about the possibility of "thermite-style" reactions occurring within cells. See the NFPA FPRF report titled, "Lithium-Ion Batteries Hazard and Use Assessment," for an in-depth analysis.

sealed seams (commonly referred to as Li-ion polymer cells[21]), as shown in Figure 4. A variety of safety mechanisms might also be included in the mechanical design of a cell, such as charge interrupt devices and positive temperature coefficient switches.[22,23]

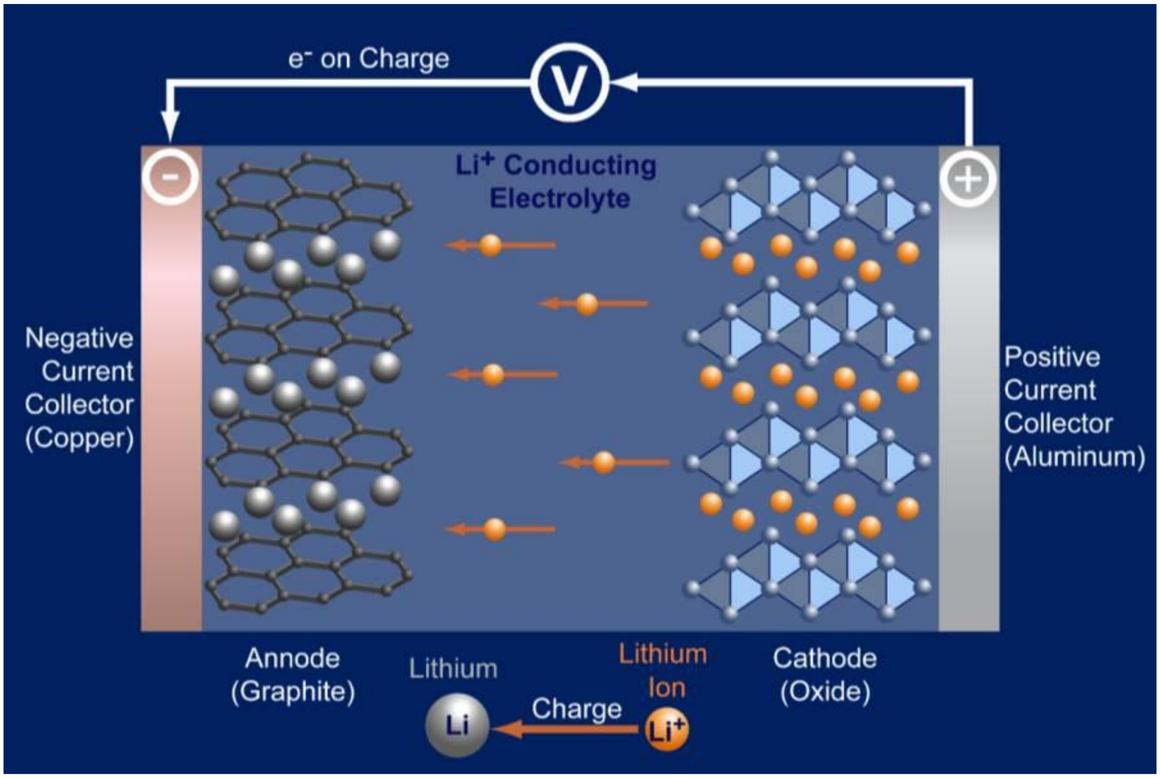

Figure 2 Li-ion cell operation: During charging, lithium ions intercalate into the anode, the reverse occurs during discharge

2.3.2 Li-ion Cell Characteristics and Hazards

The electrolyte within a typical Li-ion cell includes a volatile hydrocarbon-based liquid and a dissolved lithium salt (which is a source of lithium ions), such as lithium hexofluorophosphate. Battery cells are hermetically sealed to prevent moisture in the air from degrading the cells. Li-ion cells are not vented to the atmosphere like lead acid batteries, therefore, under normal usage

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[21] The term "lithium polymer" has been previously used to describe lithium metal rechargeable cells that utilized a polymer-based electrolyte. Lithium polymer is now used to describe a wide range of Li-ion cells enclosed in soft pouches with electrolyte that may or may not be polymer based.

[22] For a more detailed discussion of Li-ion cells see: Dahn J, Ehrlich GM, "Lithium-Ion Batteries," *Linden's Handbook of Batteries*, 4th Edition, TB Reddy (ed), McGraw Hill, NY, 2011.

[23] For a review of various safety mechanisms that can be applied to Li-ion cells see: Balakrishnan PG, Ramesh R, Prem Kumar T, "Safety mechanisms in lithium-ion batteries," Journal of Power Source, 155 (2006), 401-414.

conditions, they do not exhaust vapors. In normal usage, cell electrolyte should not be encountered by anyone handling a Li-ion battery, making the risk of a spill of electrolyte from any commercial Li-ion battery pack very remote. Furthermore, in most commercial cells, the electrolyte is largely absorbed in electrodes, such that there is no free or "spillable" electrolyte within individual sealed cells. In those instances, severe mechanical damage (e.g., severe crushing) can cause a small fraction of total electrolyte quantity to leak out of a single cell; however, any released electrolyte is likely to evaporate rapidly.

Li-ion cells are sealed units, and thus under normal usage conditions, venting of electrolyte should not occur. If subjected to abnormal heating or other abuse conditions, electrolyte and electrolyte decomposition products can vaporize and be vented from cells. Accumulation of liquid electrolyte is unlikely in the case of abnormal heating. Vented electrolyte is flammable, and may ignite on contact with a competent ignition source, such as an open flame, spark, or a sufficiently heated surface. Vented electrolyte may also ignite on contact with cells undergoing a thermal runaway reaction. Cell vent gas composition will depend upon a number of factors, including cell composition, cell state of charge, and the cause of cell venting. Vent gases may include volatile organic compounds (VOCs, such as alkyl-carbonates, methane, ethylene, and ethane), hydrogen gas, carbon dioxide, carbon monoxide, soot, and particulates containing oxides of nickel, aluminum, lithium, copper, and cobalt. Additionally, phosphorus pentafluoride (PF_5), phosphoryl fluoride (POF_3), and hydrogen fluoride (HF) vapors may form. Vented gases may irritate the eyes, skin, and throat. Cell vent gases are typically hot and upon exit from a cell, can exceed 600 ºC (1,112 ºF). Contact with hot gases can cause thermal burns.[24]

[24] Lithium-Ion Battery Emergency Response Guide, Tesla Energy Products, September 2015, Revision 02

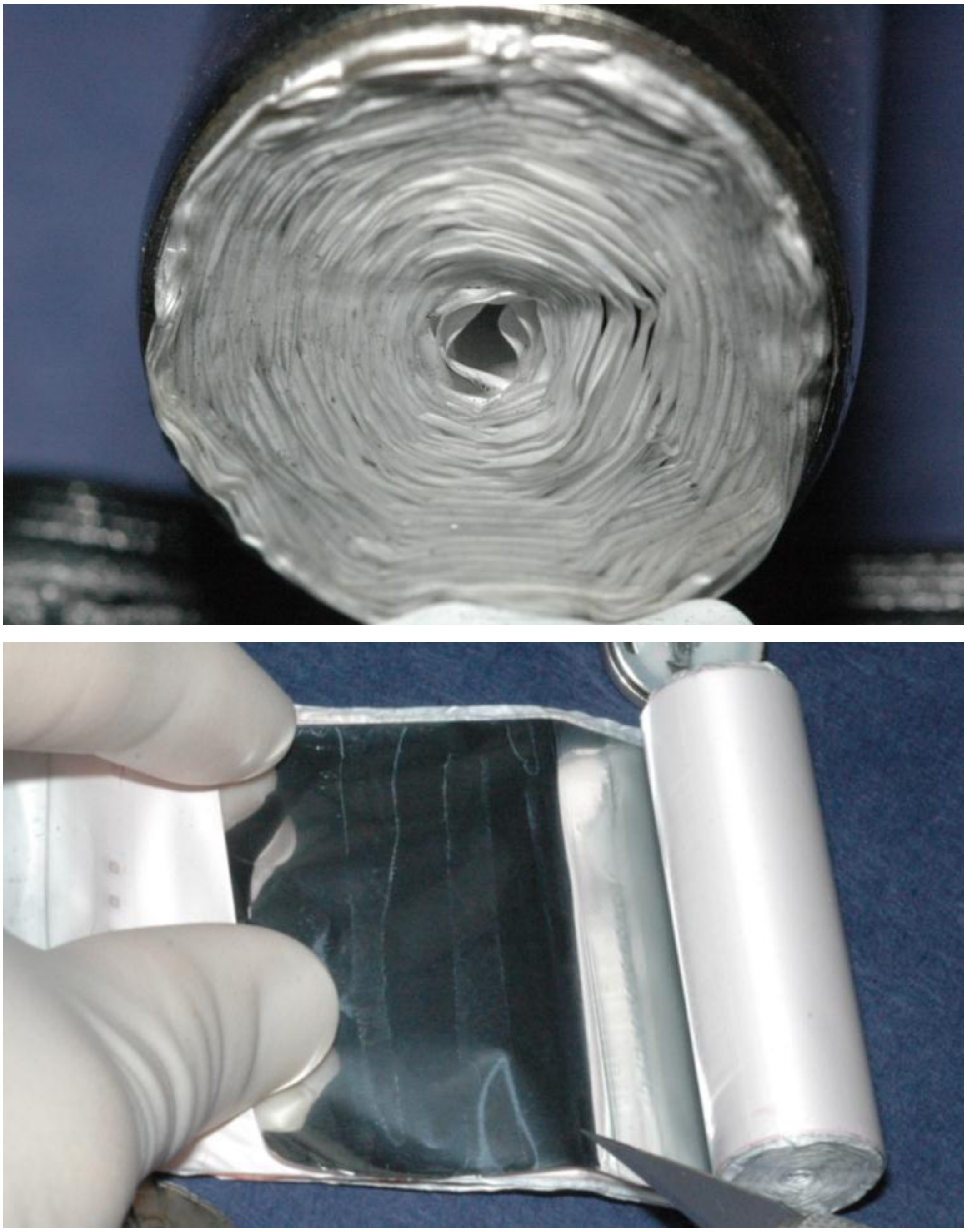

Figure 3 Base of a cylindrical Li-ion cell showing wound structure (top); Cell being unwound revealing multiple layers: separator is white, aluminum current collector (part of cathode) appears shiny (bottom)

Figure 4 Example of 18650 cylindrical cells; these are the most common consumer electronics Li-ion cell form factor (top); hard case prismatic cell (bottom left); and soft pouch polymer cell (bottom right)

2.3.3 Li-ion Battery Design

A Li-ion battery is made from multiple individual cells packaged together with their associated control system and protection electronics. By connecting cells in parallel, designers increase pack capacity. By connecting cells in series, designers increase pack voltage. Thus, most battery packs will be labeled with a nominal voltage that can be used to infer the number of series elements and, along with total battery pack energy (in watt hours [Wh]), can be used to determine the capacity (in ampere hours [Ah]) of each series element (size of individual cells or the number of cells connected in parallel). A Li-ion battery, despite conformance to a number of safety standards, may pose a significant high voltage and electrocution risk if it has been significantly damaged. Since Li-ion cells are not cycled to zero volts, a Li-ion battery pack, even in a normally discharged condition, is likely to contain substantial electrical charge. Cutting into a normally discharged battery pack can cause sparking or create electrocution hazards.

For large format battery packs, cells may be connected together (in series and/or in parallel) in modules. The modules may then be connected in series or in parallel to form full battery packs. Modules are used to facilitate readily changed configurations and easy replacement of faulty portions of large battery packs. Thus, large format battery pack architecture can be complex.

ESS batteries typically utilize many individual cells comprised into modules, which are assembled to form a large format battery pack. Large format battery packs typically contain an active safeguarding system to monitor electrical current, voltage, and temperature of the cells to optimize pack performance and mitigate potential failures, including fire. Numerous standards and protocols are available for these packs, including documents created by Underwriters Laboratories (UL), Institute of Electrical and Electronics Engineers (IEEE), National Electrical Manufacturers Association (NEMA), Society of Automotive Engineers (SAE), International Electrotechnical Commission (IEC), United Nations (UN), Japanese Standards Association (JSA), and Battery Safety Organization (BATSO). It is beyond the scope of this report to discuss all potential standards and protocols; however, a summary of the many standards and testing protocols for Li-ion cells has been published previously.[25]

2.4 ESS Codes and Standards

Exponent reviewed relevant codes and standards relating to the design, testing, and installation of Li-ion ESSs.

2.4.1 Safety Standards

In addition to the numerous standards and protocols available for Li-ion batteries, there are a number of safety standards for the overall construction of Li-ion stationary battery systems and ESSs. These safety standards generally include a minimum set of construction requirements

[25] UL, "Safety Issues for Lithium-Ion Batteries," 2012.

with which the system should comply, as well as a number of performance tests to ensure the system will operate safely over its anticipated life. These construction requirements typically address some or all of the following: material choices/requirements; electrical spacing of components; wiring criteria; controls and other components; failure modes and effects analysis **(**FMEA); and functional safety requirements, markings, signage, and instructions.

Performance tests are conducted to ensure that the Li-ion battery ESS operates safely under normal use and foreseeable misuse conditions. Some examples of performance tests include: normal operation at a variety of expected temperatures; anticipated abnormal events, such as short circuit tests or other tests for foreseeable fault conditions; electrical spacing and insulation tests, such as a dielectric voltage test; and environmental conditions, such as exposure to water or other environmental stresses.

The published safety standards for Li-ion ESSs are often divided into technology specific and/or application specific documents. Some standards are intended for specific countries or geographical regions, while others are written as international standards. For battery ESSs, many of these standards were written for more traditional technologies, such as lead acid or nickel-cadmium (NiCad) battery systems and many of the documents are in the form of guides or recommended practices rather than standards; however, they still contain valuable information for evaluating and determining the safety of the ESS. It is beyond the scope of this report to discuss in detail all of the potential standards, guides, and recommended practices; however, a summary of many testing protocols for stationary battery systems and ESSs has been published previously.[26] The following is a list of many of the relevant documents and a brief summary of those documents that directly apply[27] to Li-ion battery ESSs and/or stationary battery systems:

[26] UL, "Draft Storage/Stationary Batteries Standards List."

[27] Other documents that apply to battery ESSs or stationary battery systems that do not include Li-ion technologies within their scope were reviewed. Examples of such documents include: IEC 62485-2, *Safety Requirements for Secondary batteries and battery installations: Part 2 stationary*; IEC 60896-11, *Stationary lead-acid batteries Part 11: Vented types - General requirements and methods of tests*; IEC 60896-22, *Stationary lead-acid batteries Part 22: Valve regulated types – Requirements*; IEC 60896-21, *Stationary lead-acid batteries Part 21: Valve regulated types – Methods of test*; EN50272-2, *Safety Requirements for Secondary batteries and battery installations: Part 2 stationary*.

- UL 1973, *Batteries for Use in Light Electric Rail (LER) and Stationary Applications* (UL 1973), is a safety standard for stationary batteries for energy storage applications that is not specific to any one battery technology or chemistry, and can apply to Li-ion battery ESSs, as well as ESSs using other battery chemistries. The standard includes construction requirements, safety performance tests, and production tests.[28] The Li-ion batteries assessed in the testing described in this report are listed to UL 1973.

  UL 1973 contains a series of construction parameters, including requirements for non-metallic materials, metallic parts resisting corrosion, enclosures, wiring and terminals, electrical spacing and separation of circuits, insulation and protective grounding, protective circuits and controls, cooling/thermal management, electrolyte containment, battery cell construction, and system safety analyses.

  UL 1973 also outlines a series of safety performance tests for ESSs, including electrical tests such as an overcharge test, short circuit test, over-discharge protection test, temperature and operating limits check test, imbalanced charging test, dielectric voltage test, continuity test, failure of cooling/thermal stability system test, and working voltage measurements. In addition, UL 1973 requires testing of electrical components, including a locked-rotor test for low voltage direct current (DC) fans/motors in secondary circuits, input, leakage current, a strain relief test and a push-back relief test.

  Mechanical tests are also required by UL 1973, including a vibration test, shock test, and crush test, which only apply to LER applications. Other mechanical tests that apply to all systems include a static force test, impact test, drop impact test, wall mount fixture/handle test, mold stress test, pressure release test, and a start-to-discharge test.

  Additional environmental tests are also required by UL 1973, including a thermal cycling test, resistance to moisture test, and a salt fog test.

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[28] UL 1973, *Batteries for Use in Light Electric Rail (LER) and Stationary Applications*

Of particular relevance to this study, UL 1973 also requires two fire exposure tests: an external fire exposure test and an internal fire exposure test. The purpose of the external fire test is to ensure that an ESS will not explode as a result of being exposed to a hydrocarbon pool/brush fire. In the external test, a fully charged ESS is subjected to a heptane pool fire, or another similar hydrocarbon fuel pool fire, for 20 minutes. The fuel is held in a pan placed 24 inches under the ESS and is sized (in diameter) to be large enough to cover the dimensions of the ESS. After the 20 minute exposure, the ESS is subjected to a hose down in accordance with UL 263, *Conduct of Hose Stream Test of the Standard for Fire Tests of Building Construction and Materials*, to represent the firefighter response that the system may be exposed to during a fire. The ESS must demonstrate that no explosion hazards exist by the observation and measurement of any projectiles that occur during the external fire test.

The internal fire test is meant to demonstrate how the ESS will prevent a single cell failure within the battery system from cascading into a fire and/or explosion. In the internal fire test, the fully charged ESS is subjected to heating until thermal runaway of one internal battery cell that is centrally located within the ESS. Once the thermal runaway is initiated, the mechanism used to create thermal runaway is shut off or stopped and the ESS is subjected to a one hour observation period. Fire cannot propagate during this observation period or result in an explosion.

- IEC 61427-1, *Secondary cells and batteries for renewable energy storage - General requirements and methods of test - Part 1: Photovoltaic off-grid applications*, provides general information relating to the requirements for the secondary batteries used in photovoltaic energy systems (PVES) and the typical test methods used for the verification of battery performance. This standard deals with cells and batteries used in photovoltaic off-grid applications and is applicable to all types of secondary batteries, including Li-ion.[29]

[29] IEC 61427-1, *Secondary cells and batteries for renewable energy storage - General requirements and methods of test - Part 1: Photovoltaic off-grid applications,* 2013 Edition

- IEC 61427-2, *Secondary cells and batteries for renewable energy storage – General requirements and methods of test – Part 2: On-grid applications,* is a standard currently under development by IEC that relates to secondary batteries used in on-grid electrical energy storage (EES) applications. It provides test methods for the verification of their endurance, properties, and electrical performance in such applications. The test methods are essentially battery chemistry neutral, i.e., applicable to all secondary battery types, including Li-ion. On-grid applications are characterized by the fact that batteries are connected via power conversion devices to a regional, nation-, or continent-wide electricity grid and act as instantaneous energy sources and sinks to stabilize the grid's performance when major amounts of electrical energy from renewable energy sources are fed into it.[30]

- IEC 62619, *Secondary cells and batteries containing alkaline or other non-acid electrolytes - Safety requirements for large format secondary lithium cells and batteries for use in industrial applications,* is under development by IEC and will provide requirements on safety aspects associated with the erection, use, inspection, maintenance and disposal of cells and batteries for stationary applications and motive (other than on-road vehicles). It includes safety requirements for Li-ion cells for stationary and off-road motive applications and some battery requirements (evaluation of battery and battery management system [BMS] combination). The standard is not a system standard however, as it covers only battery and BMS interactions.

Two standards are currently under development by UL and the IEC that, when finished, will directly apply to commercial and residential Li-ion battery ESSs, including:

- UL Subject 9540, *Outline of Investigation for Energy Storage Systems and Equipment* (UL 9540), which will cover various types of ESSs and is not specific to just one battery chemistry or technology. Its scope includes requirements for ESSs that are intended to store energy from power or other sources and provide electrical or other types of energy

[30] IEC 61427-2, *Secondary cells and batteries for renewable energy storage – General requirements and methods of test – Part 2: On-grid applications,* 2015 Edition

to loads or power conversion equipment. The ESSs may include equipment for charging, discharging, control, protection, communication, controlling the system environment, fuel or other fluid movement and containment. The system may be standalone to provide energy for local loads or can be in parallel with an electric power system, electric utility grid or applications that perform multiple operational modes. The standard contains a series of construction parameters with material flammability criteria and performance tests for ESSs. Although no full-scale fire test of the ESS as an assembly is required, UL 9540 does require that Li-ion ESSs meet the requirements of UL 1973, which contains two fire tests, as described previously.[31]

- IEC 62897, *Stationary Energy Storage Systems with Lithium Batteries – Safety Requirements*, is under development by IEC and will provide general safety requirements for stationary ESSs with lithium batteries. The standard will incorporate a number of requirements to address potential hazards with ESSs, including: electric shock or burn; mechanical hazards; spread of fire from the equipment; excessive temperature; effects of fluids and fluid pressure; liberated gases, explosion; and chemical hazards (e.g., electrolyte). The standard intends to cover small battery systems for residential or similar use that can be connected to a main source of supply.[32,33]

2.4.2 Codes and Regulations

In addition to safety standards, there are local, state, and national electrical, building, and fire codes to consider that could impact the installation of ESSs. In the United States, the codes affecting ESSs include the electrical installation codes, such as NFPA 70, *National Electrical Code* (NEC) and fire codes, such as NFPA 1, *Fire Code* (NFPA 1) or the International Code Council (ICC) code suite for building and fire codes. Electrical codes, such as the NEC, include requirements, among others, for wiring methods, grounding criteria, signage, and enclosures that impact ESS electrical safety.[34] Building and fire codes include requirements for battery

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[31] UL 9540, *Outline of Investigation for Energy Storage Systems and Equipment*, Issue Number 1, June 30, 2014.

[32] http://www.iec.ch/dyn/www/f?p=103:38:0::::FSP_ORG_ID,FSP_APEX_PAGE,FSP_LANG_ID, FSP_PROJECT:1410,23,25,IEC%2062897%20Ed.%201.0

[33] UL, "Draft Storage/Stationary Batteries Standards List."

[34] NFPA 70, 2014 Edition, Article 480, *Storage Batteries*

rooms, spill containment, and fire protection systems for areas containing battery storage that impact the fire risk of the building, its occupants, and contents.

Concerns have arisen from the perceived lack of information contained in local, state, and national codes and regulations as they relate to Li-ion ESSs. Some of the concerns include: (1) limited information in the codes specifically relating to Li-ion batteries; (2) volume of electrolyte in the Li-ion battery being used to define its hazard level (which is not appropriate for Li-ion battery chemistry[35]); (3) fire suppression and detection systems required to protect ESSs; (4) whether or not these batteries are considered hazardous materials; and (5) separation of ESSs from other portions of the building.

2.4.2.1 Electrical Codes

NEC Article 480, *Storage Batteries*, applies to all stationary installations of storage batteries. Article 480 was originally written for and generally applied to stationary lead acid battery installations in the range of 48 volts. The section outlines a series of requirements for battery installations, however, most pertain to the electrical safety of the systems and have limited requirements specific to fire protection that would address the industry concerns listed above. For example, the NEC has sections on battery and cell terminations (Section 480.3), wiring and equipment supplied from batteries (Section 480.4), overcurrent protection (Section 480.5), disconnect methods (Section 480.6), insulation (Section 480.7), racks and trays that support the batteries (Section 480.8), battery locations (Section 480.9 Parts (A) , (B), and (G)), and safety vents[36] (Section 480.10). Section 480.9, *Battery Locations*, Parts (C) and (D) requires certain working spaces clearances for battery systems to allow for the units to be properly accessed. In addition, Part (E) requires that personnel door(s) intended for entrance to and egress from rooms designated as battery rooms open in the direction of egress and be equipped with listed panic

[35] There are a number of reasons why the "volume of electrolyte" is not appropriate. One example is that the volume of electrolyte inside a battery cell is not extractable from a completed cell; therefore, the volume of electrolyte inside a Li-ion cell does not meaningfully translate to a hazard. The volume of electrolyte is appropriate for other chemistries, such as lead acid, where the failure of a battery could lead to spilling of the aqueous solution; however, the failure of a Li-ion battery or cell will more likely lead to the venting of a flammable gas, not the release of a liquid.

[36] Li-ion batteries do not typically require venting due to their technology and design, which does not vent hydrogen.

hardware. Gas piping is also prohibited from being installed within a dedicated battery room in Section 480.9 Part (F).

The next edition of the NEC to be published, the 2017 edition, is proposed to have a new article (Article 706) dedicated to ESSs. This addition should further assist installers, AHJs and manufacturers with navigating the electrical installation requirements for these systems.

2.4.2.2 Building and Fire Codes

Below is a summary of the sections contained within the 2015 edition of the International Building Code (IBC), International Residential Code (IRC), International Fire Code (IFC), and NFPA 1 relating to Li-ion ESSs and the concerns listed above. Many of the identified gaps in the codes mentioned below are currently being worked on and may be addressed when the next round of codes are published.

1. **Limited information on Li-ion battery ESSs.** Recent additions to the building and fire codes have answered many industry concerns, providing more details and thresholds for when requirements are necessary for Li-ion battery systems. Starting in 2006 for the IFC and 2009 for NFPA 1,[37,38] Li-ion batteries for use in stationary storage battery systems were discussed. Many municipalities lag behind in the adoption of new editions of building and fire codes. As such, those areas still using older versions of the codes could encounter issues; however, this issue (besides the correlating issues highlighted below in #2) is one that should resolve itself with the adoption of the newer codes.

   The 2015 edition of the IRC does not contain language relating to stationary battery systems, ESSs, or other similar systems, which could be confusing for readers looking for guidance for systems being installed in one or two-family dwellings or townhouses.

2. **Volume of electrolyte.** Traditionally, the IBC, IFC, and NFPA 1 applied specific safety requirements to battery systems containing more than 50 gallons of electrolyte. However, this requirement cannot be applied to Li-ion battery systems, as the electrolyte

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[37] 2006 IFC, Section 608.1

[38] NFPA 1, 2009 Edition, Section 52.1

is not stored in an aqueous solution. To account for this, starting in 2006 for the IFC and 2009 for NFPA 1, the fire codes defined the threshold at which requirements are necessary for Li-ion stationary storage battery systems according to their weight (1,000 pounds).[39,40] Adding to some of the confusion in the marketplace when discussing Li-ion battery packs and how best to define/categorize them, other agencies beyond the ICC and NFPA also utilize varying methods. For instance, the United Nations, *Recommendations on the Transport of Dangerous Goods - Manual of Tests and Criteria*, also defines and categorizes batteries by mass, where anything larger than 12 kilograms (kg) of gross mass is a "large battery" and anything less than 12 kg is a "small battery." In addition, a "large cell" is defined as anything with a gross mass greater than 500 grams (g). A cell less than 500 g is considered a "small cell."[41] The Department of Transportation (DOT) in 49 CFR 173.185 defines and categorizes batteries by "equivalent lithium content" (ELC), where the ELC is the product of the rated capacity, in Ah, of a Li-ion cell times 0.3, with the result expressed in grams. The ELC for a battery pack equals the sum of the grams of ELC contained in the component cells of the battery.[42] As such, DOT categorizes Li-ion batteries by their capacity, not the volume of electrolyte or mass of the cell or battery pack.

Even with the addition of the weight threshold for Li-ion battery systems in 2006 and 2009, the IBC, IFC, and NFPA 1 each still contain language in other sections of the codes that discuss requirements when the volume of electrolyte is above the 50-gallon threshold, not taking into account the weight of a Li-ion battery system. Three instances identified in the codes where this occurs include:

a. IBC Section 907.2.23, which states that any battery room with greater than 50 gallons of electrolyte must have a smoke detection system. IFC Section 608 applies directly to stationary storage battery systems and Li-ion batteries and resolves any confusion that exists in the code, as Section 608.9 requires a smoke

[39] 2006 IFC, Section 608.1

[40] NFPA 1, 2009 Edition, Section 52.1

[41] United Nations, *Recommendations on the Transport of Dangerous Goods - Manual of Tests and Criteria*

[42] 49 CFR 171.8

detection system for stationary battery systems that are large enough to trigger the thresholds, such as a Li-ion battery system greater than 1000 pounds.[43] However, if a reader were to miss that section of the IFC, and only read the section in the IBC, it could create confusion over how to apply section 907.2.23 to Li-ion battery systems.

b. IFC Section 105.7.2, which states that battery systems with more than 50 gallons of electrolyte require a permit before installation. However, no weight threshold is provided for Li-ion batteries.[44] As such, there could be confusion regarding whether or not a permit is required for Li-ion battery systems.

c. NFPA 1 Table 1.12.8(a), which states that lead-acid battery systems with more than 50 gallons (unsprinklered buildings) or 100 gallons (spinklered buildings) of electrolyte require a permit before installation. However, Li-ion battery systems are not addressed in Table 1.12.8(a).[45] As such, there could be confusion regarding whether or not a permit is required for Li-ion battery systems.

3. **Suppression and detection.** Where required, such as for a high-rise building, fire sprinklers are not required in the area where battery systems are installed, provided the space is equipped with an automatic fire detection system and is separated from the rest of the building with one hour barriers or two hour horizontal assemblies.[46] In addition, a smoke detection system is required for all Li-ion battery systems greater than 1,000 pounds.[47,48]

4. **Hazardous materials.** The IBC and NFPA 1 state that battery systems do not fall into the Hazardous Group H category (for the IBC) or should be considered a hazardous material (for NFPA 1) provided certain ventilation requirements for the ESS are met.[49,50]

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[43] 2015 IFC, Section 608.1 and 608.9

[44] 2015 IFC, Section 105.7.2

[45] NFPA 1, 2015 Edition, Table 1.12.8(a)

[46] 2015 IBC, Section 403.3 and Exception to Section 903.2

[47] 2015 IFC, Section 608.9

[48] NFPA 1, 2015 Edition, Section 52.3.10

[49] 2015 IBC, Section 307.1.1(9)

However, Li-ion batteries typically do not require room ventilation,[51] as off gassing does not occur during normal operation. It is unclear if the IBC and NFPA 1 requirement for room ventilation is necessary for a Li-ion battery ESS to ensure it does not fall into the hazardous category.

5. **Separation.** The IBC states that Li-ion battery systems more than 1,000 pounds in weight shall be separated from the remainder of the building by either a one hour separation or two hour separation depending on the occupancy in which it is installed.[52]

Section 608 of the IFC and Chapter 52 of NFPA 1 provide further guidance on the proper installation of Li-ion ESSs. However, many of the requirements do not apply to Li-ion due to the chemistry of battery, including safety caps, spill control and neutralization measures, and room ventilation. Signage, seismic protection, and a fire/smoke detection system are required for Li-ion battery systems larger than 1,000 pounds.[53,54] A review of these two sections also identified another potential area of confusion for a user of the codes. The IFC does not require thermal runway protection for Li-ion battery systems, while NFPA contains contradictory guidance. Thermal runaway can occur in Li-ion battery systems and it is unclear why thermal runaway protection in Li-ion battery systems is not required in the IFC. NFPA 1 Table 52.1 states that Li-ion battery systems do not require thermal runaway protection; however, Section 52.3.2 states that Li-ion battery systems, "shall be provided with a listed device or other approved method to preclude, detect, and control thermal runaway." Table 52.1 and the language of Section 52.3.2 are in direct conflict with one another, leading to possible confusion for anyone using the code. A review of the Report on Proposals and Report on Comments from the 2009 NFPA 1 code development cycle provided some guidance regarding what the technical committee intended. It appears that the technical committee intended for the thermal runaway protection to be required; however, a typo in Table 52.1 was not fixed at the time of initial adoption or anytime during future code development cycles. This issue should be addressed in

[50] NFPA 1, 2015 Edition, Section 60.1.2

[51] 2015 IFC, Table 608.1 and NFPA 1, 2015 Edition, Table 52.1

[52] 2015 IBC, Table 509

[53] 2015 IFC, Table 608.1

[54] NFPA 1, 2015 Edition, Table 52.1

the next code development cycle to remove any confusion as to what NFPA 1 requires for thermal runaway protection of Li-ion battery systems.

2.5 ESS Fire Incidents

A review of fire incidents reported in the National Fire Incident Reporting System (NFIRS) from 1999 to 2013 was performed during the literature review. During this time period, only 44% of fires that fire departments respond to were captured in NFIRS. Thus, the numbers listed below do not account for every fire in the United States during that time. In addition, NFIRS currently does not have a means to report a stationary battery system or ESS fire; however, they do have a coding system for uninterrupted power supplies (UPS; code 226) and batteries (code 229). Table 1 provides a summary of the number of UPS and battery fires that were reported in NFIRS between 1999 and 2013.

Table 1 Summary of NFIRS Data

Incident Type	UPS Fire (Code 226)	Battery Fire (Code 229)
Structure Fire or Fire in Mobile Property used as a Fixed Structure	142	318
All Fires (not just Structures)	227	1,014

Exponent also searched for public incidents tied directly to the involvement of Li-ion ESSs in a fire. Through this search, only two major events involving battery ESSs were identified, one at a wind turbine power generating facility in Hawaii and one at a solar energy facility in Arizona. However, only the Arizona facility contained a Li-ion battery ESS, which was a pilot ESS that the facility was testing. Summaries of these two incidents ascertained from public sources are provided in the following sections.

No publically reported fire incidents were identified to have started in or significantly involved a commercial or residential ESS.

2.5.1 Kahuku Wind Energy Storage Farm Battery ESS Fires

Three fires occurred at the Kahuku Wind Energy Storage Farm over the course of a year and a half span from April 2011 to August 2012. The ESS contained 12,000 individual lead acid battery packs for a capacity of 15 megawatts (MW). The battery packs were stacked six feet high inside a 9,000 square foot metal warehouse building. It was determined that the fires were caused by undersized capacitors used by the battery system. The first two fires were allowed to self-extinguish, with limited damage to the system and the building; however, the third fire resulted in a total loss of the building and contents, including the 12,000 battery packs.[55,56,57]

The first incident occurred on April 22, 2011; the alarm was received by dispatch at approximately 5:45 p.m. and the Honolulu Fire Department (HFD) arrived on scene approximately 10 minutes later. An engineer from Xtreme Power, Inc. (Xtreme) was alerted by a remote alarm indicating that an exhaust fan on the Hawaiian Electric Company (HECO) side of the structure had overheated. The engineer also stated that smoke and popping sounds were emanating from the structure before HFD arrived. When HFD arrived, they noted smoke coming from the battery storage building. Approximately an hour after the first alarm, other arriving HFD personnel reported moderate grayish black smoke emanating from the structure, with no flames visible and no other structures in immediate danger. Facility personnel provided battery safety data sheets (SDS) for the lead acid batteries and building plans, however, HFD chose to wait for daylight to make an interior attack, primarily due to concerns regarding the stored energy in the batteries and possibly unsafe night operations. Major hazards identified by Xtreme and HFD included the batteries themselves (possibly explosive or energized), the sulfuric acid from the batteries, toxic environment, and energized electrical equipment. Xtreme advised HFD that water could not be used to extinguish the fire and that dry chemical, carbon dioxide (CO_2), or specialty foam (FM200) would be the best extinguishing agent. HECO personnel arrived on scene to secure the power to the building and advised of a sulfuric acid odor at the HECO switch box, emanating from the conduits within the building. A firewatch was present throughout the night. The following day, HFD made entry into the building, but no

[55] http://www.windpowermonthly.com/article/1284038/analysis-first-wind-project-avoids-storage-30m-fire

[56] http://www.greentechmedia.com/articles/read/Battery-Room-Fire-at-Kahuku-Wind-Energy-Storage-Farm

[57] http://www.scientificamerican.com/article/battery-fires-pose-new-risks-to-firefighters/

active burning was found. The building was ventilated and cleared and operators of the facility were allowed to investigate and notified HFD that the cause of the incident was a failed electrical inverter. HFD investigators concluded that the origin of the fire was in the battery ESS building, within the Inverter #9 cabinet. The first material ignited was most likely conductor insulation or associated components within the cabinet. The fire was classified as accidental, failure and/or malfunction of operating electrical equipment. Fire spread was confined to the object of origin.[58]

The second incident occurred on May 23, 2011; the alarm was received by dispatch at approximately 10:20 p.m. and HFD arrived on scene approximately 10 minutes later. When HFD arrived, they noted light smoke coming from the top of a roll up door at the same ESS building. Facility personnel advised HFD that the incident appeared to be the same as the first loss; therefore, the same actions were taken, including shutting down the power and closing the building until morning. The next morning, HFD arrived to no smoke. The building was ventilated and one inverter was found to be burned out, with no residual signs of heat.[59]

The third incident occurred on August 1, 2012; the alarm was received by dispatch at 4:44 a.m. and HFD arrived on scene approximately 15 minutes later. First Wind advised HFD that their sensors indicated the malfunction of an electrical inverter directly adjacent to the stacks of batteries in the ESS building. Due to the large amount of batteries stored on site and experiences in the prior incidents, HFD chose to standby and monitor the building until HECO arrived with their dry chemical extinguishing truck. The fire was monitored using a thermal imaging camera and smoke and heat intensified, eventually venting through the roof, with some flames visible. Water was used to cool the uninvolved side of the building, but was discontinued due to the risk of contact with the burning batteries. Once HECO arrived, HFD assisted with deploying the dry chemical extinguishing line; however, suppression efforts were unsuccessful, as the dry chemical could not reach all of the burning material and entry could not be made due to the hazardous conditions created by the burning batteries and lack of an adequate supply of dry chemical. The fire eventually involved the entire building. Water was

[58] Honolulu Fire Department Incident Report 2011-0018972.

[59] Honolulu Fire Department Incident Report 2011-0023875.

used to prevent spread to adjacent buildings, however, water could not be applied to the incident building due to environmental concerns regarding runoff water, as well as the high potential for stored electrical energy in the malfunctioning system and the large quantities of sulfuric acid involved; therefore, the fire was contained to the original building and allowed to burn until it eventually self-extinguished. HFD noted that significant/unusual fuel load from contents was a factor in suppressing the fire; with the material contributing most to flame spread being plastic used as electrical wire, cable insulation. HFD investigators concluded that the origin of the fire was in the battery ESS building. The first alarm activation was within the Inverter #9 cabinet, followed by general building smoke alarm activation. Video taken inside the ESS building showed fire in the proximity of the Inverter #9 cabinet. The first material ignited was most likely conductor insulation or associated components within the cabinet. The physical construction of the 12,000 batteries and associated conductors contributed mostly to fire spread. The fire was classified as accidental, failure and/or malfunction of operating electrical equipment.[60]

These fires demonstrate the need for better understanding of ESS fires so that the owner and fire departments responding to these incidents can better prepared in the event of a fire.

2.5.2 Arizona Public Service Company ESS Fire

In November of 2012, a fire occurred at a state-of-the-art solar energy storage system the Arizona Public Service Company (APS) was testing. The system, the relative size of a shipping container with a capacity of 1.5 MW, had been running since February of 2012. Similar to the First Wind fires, fire department personnel allowed the fire to burn freely for some time. The cause of the fire was not reported.[61,62] Exponent requested the local fire department reports on these fire incidents to obtain further details of the incidents, however, no response was received.

To date, relatively few ESS systems have been commissioned. In addition, most systems commissioned have been lead acid battery systems, not Li-ion. The search for fires involving

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[60] Honolulu Fire Department Incident Report 2012-0038895.

[61] http://www.energy-storage-online.com/cipp/md_energy/custom/pub/content,oid,1133/lang,2/ticket,g_u_e_s_t/~/APS_fire_probed.html

[62] http://azdailysun.com/news/local/aps-fire-probed/article_1de2e924-ab0a-5e71-9a3a-6942c2d1c9bb.html

ESSs has identified only a few from publically available sources. In order to gain insight into how Li-ion ESSs will behave in fire scenarios, we can examine fires involving similar systems or battery fires in general.

2.6 Li-ion Battery Fires

Given the lack of ESS fire incidents documented in the literature, a review of Li-ion battery fires was conducted. Fires may occur in an ESS high voltage battery, or a fire may extend to the battery, attacking the ESS from the outside in. Previous research programs have been conducted focusing on large format Li-ion battery fires, electric drive vehicle (EDV) Li-ion battery fires, and Li-ion battery storage fires. This research involved full-scale fire tests of Li-ion batteries that were polymer, prismatic, and cylindrical designs.

For large format Li-ion battery systems with polymer or prismatic designs, the research has generally shown the following hazards associated with fires:

1. Fire tests of identical vehicles indicated that the heat release rate (HRR) of an EDV compared to a more common internal combustion engine (ICE) vehicle are similar[63] and a free burn (no suppression) test of an EDV battery did not produce significant HRRs.[64]

2. Test results indicate that water can be an effective extinguishing agent on large format Li-ion battery fires, however, large quantities may be required for extinguishment.[65,66,67]

3. During fires tests of EDVs with polymer pouch battery cells, no projectiles or explosions from the large format batteries were observed. [68,69,70]

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[63] Lecocq, A, Bertana M, Truchot, B. and Marlair G. “Comparison of the Fire Consequences of an Electric Vehicle and an Internal Combustion Engine Vehicle.” INERIS – National Institute of Industrial Environment and Risks, Verneuil-en-Halatte, France. Second International Conference on Fires in Vehicles, September 27-28, 2012, Chicago, IL.

[64] Long RT, Blum AF, Bress TJ, and Cotts BRT. “Emergency response to incidents involving electric vehicle battery hazards.” Fire Protection Research Foundation Report, July 2013.

[65] Delphi Corporation. Hybrid Electric Vehicles for First Responders. Troy, MI. 2012.

[66] Long RT, Blum AF, Bress TJ, and Cotts BRT. “Emergency response to incidents involving electric vehicle battery hazards.” Fire Protection Research Foundation Report, July 2013.

[67] Egelhaaf, M., Kress, D., Wolpert, D., Lange, T., Justen, R., and Wilstermann, H., "Fire Fighting of Li-Ion Traction Batteries," SAE Int. J. Alt. Power. 2(1):37-48, 2013, doi: 10.4271/2013-01-0213.

4. Gas samples collected during fire tests of complete (i.e., full) ICE vehicles and EDVs identified similar levels of toxic compounds in the smoke, including CO_2, nitrogen oxides (NO_x), hydrogen cyanide (HCN), hydrogen chloride (HCl), carbon monoxide (CO), and hydrogen fluoride (HF).[71] In addition, water samples collected after extinguishing Li-ion batteries showed concentrations of fluoride and chloride.[72,73]

5. Fire tests have also demonstrated that in the tested scenario, with a battery pack tested inside a vehicle fire trainer (i.e., not a powered consumer EDV), the shock/electrocution hazards of applying a water stream directly to an energized high voltage battery that has been compromised by heat and fire were negligible.[74] In addition, other fire tests where hose streams were applied directly to energized electrical equipment have demonstrated that current leakage through the suppression water is not a hazard, provided sufficient clearance distances for the given voltage of the electrical equipment are observed between the hose stream and conductors.[75,76,77,78]

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[68] Long RT, Blum AF, Bress TJ, and Cotts BRT. “Emergency response to incidents involving electric vehicle battery hazards.” Fire Protection Research Foundation Report, July 2013.

[69] Watanabe, N., Sugawa, O., Suwa, T., Ogawa, Y., Hiramatsua, M., Tomonoria, H., Miyamotoa, H., Okamotoa, K., and Honmaa, M. “Comparison of fire behaviors of an electric-battery-powered vehicle and gasoline-powered vehicle in a real-scale fire test.” National Research Institute of Police Science, Japan. Presented at Second International Conference on Fires in Vehicles, September 27-28, 2012, Chicago, IL.

[70] Lecocq, A, Bertana M, Truchot, B. and Marlair G. “Comparison of the Fire Consequences of an Electric Vehicle and an Internal Combustion Engine Vehicle.” INERIS – National Institute of Industrial Environment and Risks, Verneuil-en-Halatte, France. Second International Conference on Fires in Vehicles, September 27-28, 2012, Chicago, IL.

[71] Lecocq, A, Bertana M, Truchot, B. and Marlair G. “Comparison of the Fire Consequences of an Electric Vehicle and an Internal Combustion Engine Vehicle.” INERIS – National Institute of Industrial Environment and Risks, Verneuil-en-Halatte, France. Second International Conference on Fires in Vehicles, September 27-28, 2012, Chicago, IL.

[72] Long RT, Blum AF, Bress TJ, and Cotts BRT. “Emergency response to incidents involving electric vehicle battery hazards.” Fire Protection Research Foundation Report, July 2013.

[73] Egelhaaf, M., Kress, D., Wolpert, D., Lange, T., Justen, R., and Wilstermann, H., "Fire Fighting of Li-Ion Traction Batteries," SAE Int. J. Alt. Power. 2(1):37-48, 2013, doi: 10.4271/2013-01-0213.

[74] Long RT, Blum AF, Bress TJ, and Cotts BRT. “Emergency response to incidents involving electric vehicle battery hazards.” Fire Protection Research Foundation Report, July 2013.

[75] Factory Mutual Handbook of Industrial Loss Prevention, “Electrical Conductivity of Extinguishing Agents”

[76] Sprague, C.S. and C.F. Harding. “Electrical Conductivity of Fire Streams” Research series no. 53. Engineering Experiment Station, Purdue University Lafayette, Indiana, January 1936.

[77] Bolander, G.G., Jughes, J. T., Toomey, T. A., Carhart, H.W., and J.T. Leonard. “Use of Seawater for Fighting Electrical Fires” Navy Technology Center for Safety and Survivability, Chemistry Division. May 25, 1989.

Previous research focusing on large format Li-ion battery fires with a polymer or prismatic design demonstrated that that some of the common concerns regarding Li-ion battery fires (namely explosions, projectiles, and toxic gas formation) have not been replicated in full-scale fire tests. However, fire tests of unconfined Li-ion batteries with a cylindrical design have demonstrated that "cell explosions" can occur with projectiles observed traveling up to 133 feet.[79]

2.7 Gap Analysis

Based upon the literature review conducted to date, Exponent has identified the following gaps in the knowledge base for commercial and residential Li-ion ESSs:

1. No public fire test data demonstrating the fire behavior of ESSs.

2. Limited public fire test data related to large format battery packs with cylindrical design utilized either in vehicles or storage systems.

3. No fire test data or publically available real world fire incidents involving residential or commercial Li-ion ESSs illustrating the hazards (projectiles, heat release, toxic gas production) to first responders and/or the best practices for fire department operations.

4. Limited real world fire incidents involving large-scale (grid size) ESSs.

5. No Li-ion ESS guidance in the IRC.

6. Some sections of the IBC, IFC, and NFPA 1 are confusing, as only the volume of the electrolyte (a requirement for older battery chemistries such as lead acid) and not the weight of the Li-ion battery system, is used as a threshold for when certain building or fire code requirements are necessary. In addition, other agencies, such as the United Nations and DOT, have other methods for defining and categorizing batteries. Many of

[78] Backstrom, R., Dini, DA, "Firefighter Safety and Photovoltaic Installations Research Project." Underwriters Laboratories Inc. November, 2011.

[79] Webster, H, "Preliminary Full-Scale Fire Tests with Bulk Shipments of Lithium Batteries." 2012 FAA Fire Safety Highlights, US Department of Transportation Federal Aviation Administration, 2012.

these code sections are presently being revised and could be addressed by the next published code set.

7. NFPA 1 provides contradictory guidance regarding thermal runway protection for Li-ion battery systems, while the IFC does not require thermal runaway protection for Li-ion battery systems at all. Many of these code sections are presently being addressed and could be resolved by the next published code set.

8. No post-fire incident response and recovery (i.e., overhaul) procedures.

9. No stationary battery system or ESS fire reporting code in NFIRS to assist in analyzing fire incidents and differentiate battery systems from household batteries.

3 Testing Program Summary

Exponent, in conjunction with the Project Technical Panel, their advisory groups, and industry sources, identified and procured two (2) Li-ion battery ESSs for full-scale testing. The battery pack utilized in the ESS is a 100 kWh unit manufactured by Tesla Energy (Tesla) meant for commercial applications (Powerpack). The Powerpack consists of a 52-inch long by 38-inch wide by 86-inch tall steel cabinet containing the battery, protection electronics, and thermal management systems. The total weight of the unit is 3,970 pounds and it mounts directly to a concrete pad. A more detailed description of the ESS tested is provided in Section 4.

The full-scale fire tests were separated into two categories: (1) external ignition of the Powerpack and (2) internal ignition of the Powerpack. During the external ignition test, the Powerpack was exposed to an external fire source (a propane burner) to simulate a fire scenario where a fire originates outside of the Powerpack. During the internal ignition test, individual battery cells within the Powerpack were forced into thermal runaway.

3.1 Test Instrumentation Summary

Both tests were performed outdoors in open air, on a concrete pad, exposed to natural weather conditions, as would be typical of an outdoor commercial installation. In the external ignition testing, a propane burner system was used to apply the thermal assault to the Powerpack and cause thermal runaway of the batteries within. During internal ignition testing, the batteries of the Powerpack were forced into thermal runaway at the individual cell level.

Data collected during the tests included:

- Internal and external Powerpack surface temperatures;
- Heat fluxes at varying stand-off distances from the Powerpack;
- Internal Powerpack cabinet and pod pressures;
- Select products of combustion;
- Weather conditions;

- Projectile observations;
- Still photography; and
- High definition video.

3.2 Full-scale Fire Protocols

Exponent and Tesla created two protocols for the full-scale fire tests: one for the external ignition test and one for the internal ignition test.

3.2.1 External Ignition Testing

The test protocol for the external ignition testing was as follows:

1. The Powerpack was positioned and the test equipment was set up as described in Section 3.1.

2. The following background data was collected as a steady-state baseline for 3 minutes:

    a. Thermocouples;

    b. Heat flux gauges; and

    c. Gas sampling.

3. High definition video recordings were started simultaneously with data collection.

4. After the 3-minute baseline was established, the propane burners were ignited to provide a 400 kW[80] exposure.

5. The 400 kW exposure was continued for approximately 60 minutes. Once at least twenty (20) cell thermal runaways were confirmed audibly, the burner was turned off.

6. Once the burner was shut off at the end of the approximate 60-minute 400 kW exposure, the progression of the Powerpack fire in the free burn state was monitored thereafter.

7. Visual observations of importance were recorded, including when smoke was first observed, when cells went into thermal runaway, smoke production/color, projectiles, when flames were first observed, height and severity of flames, etc.

8. Still photographs were recorded throughout the test, as appropriate.

[80] HRR from the propane burners was determined based upon the flow rate of propane recorded by a mass flow meter during testing times the heat of combustion of propane.

9. Data collection continued until all signs of combustion ceased.

3.2.2 Internal Ignition Testing

The test protocol for the internal ignition tests was as follows:

1. The Powerpack was positioned and the test equipment was setup as described in Section 3.1.
2. The following background data was collected as a steady-state baseline for approximately 1.5 minutes:
    a. Thermocouples and
    b. Gas sampling.
3. High definition video recordings were started simultaneously with data collection.
4. After the 1.5-minute baseline was established, multiple Powerpack cells were forced into thermal runaway through the use of heater cartridges by Tesla.
5. Visual observations of importance were recorded, including when smoke was first observed, when cells went into thermal runaway, smoke production/color, projectiles, when flames were first observed, height and severity of flames, etc.
6. Still photographs were recorded throughout the test, as appropriate.
7. Data collection continued until all signs of thermal runaway ceased.

4 ESS Description

This section provides an overview of the Powerpack (a 100 kWh commercial ESS) utilized for this testing program. The Powerpack can be a single standalone unit, as shown in Figure 5, or installed side by side with multiple Powerpacks if additional storage capacity is desired, as shown in Figure 6.

Figure 5 Single standalone Powerpack (100 kWh commercial ESS)

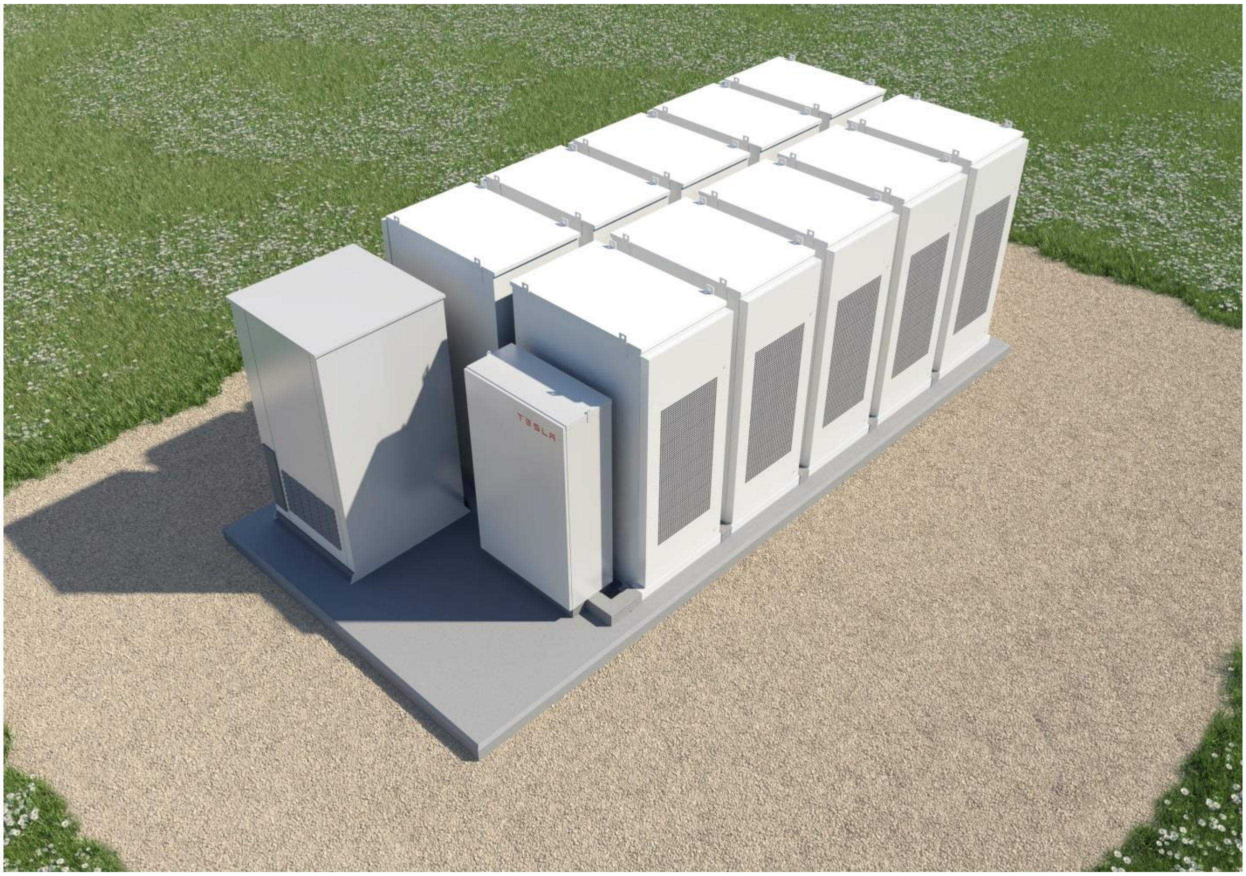

Figure 6 Multiple Powerpacks installed side by side in an array

4.1.1 ESS Battery Pack

The cells utilized within the Powerpack are 3.6 volt, 2.4 amp hour cylindrical 18650 cells. Two modules, each consisting of approximately 450 cells, are connected and enclosed inside a steel cover to form one energy storage pod, as shown in Figure 7. As such, one energy storage pod contains a total of two modules, or approximately 900 battery cells. Sixteen (16) energy storage pods are contained within the Powerpack cabinet for a total of approximately 14,400 battery cells within the Powerpack.

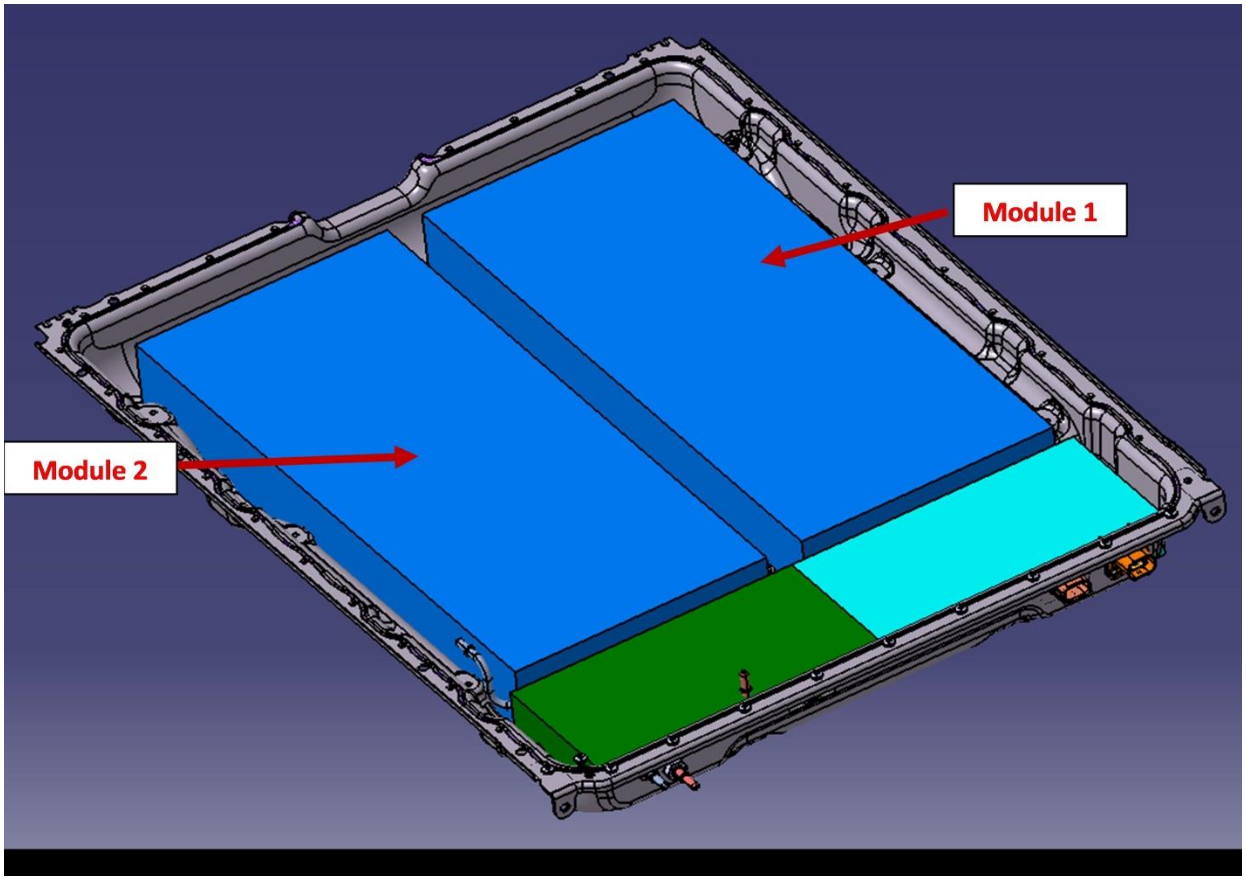

Figure 7 Illustration of a pod with two modules (blue); each module contains approximately 450 cylindrical Li-ion battery cells totaling 900 battery cells for each pod

4.2 ESS Design Layout

The Powerpack was designed for commercial installations. Within the Powerpack, Li-ion cells are contained within energy storage pods. The energy storage pods are housed inside a 52-inch long by 38-inch wide by 86-inch high steel cabinet. The total weight is 3,970 pounds. The front door of the Powerpack cabinet provides access to each of the 16 energy storage pods, as shown in Figure 8, and contains equipment designed to thermally cool the pods. The liquid cooling system pumps a 50% water / 50% ethylene glycol mixture to each of the 16 energy storage pods, as shown in Figure 9. The coolant pumps, reservoirs, and associated fans and radiators are mounted and contained within the front door of the Powerpack. A refrigerant system using 400 grams of R134a further cools the ethylene glycol and is also mounted on the front door of the Powerpack. The back of the energy storage pods connect to an exhaust manifold at the rear of the Powerpack that has a vent at the top, as shown in Figure 10.

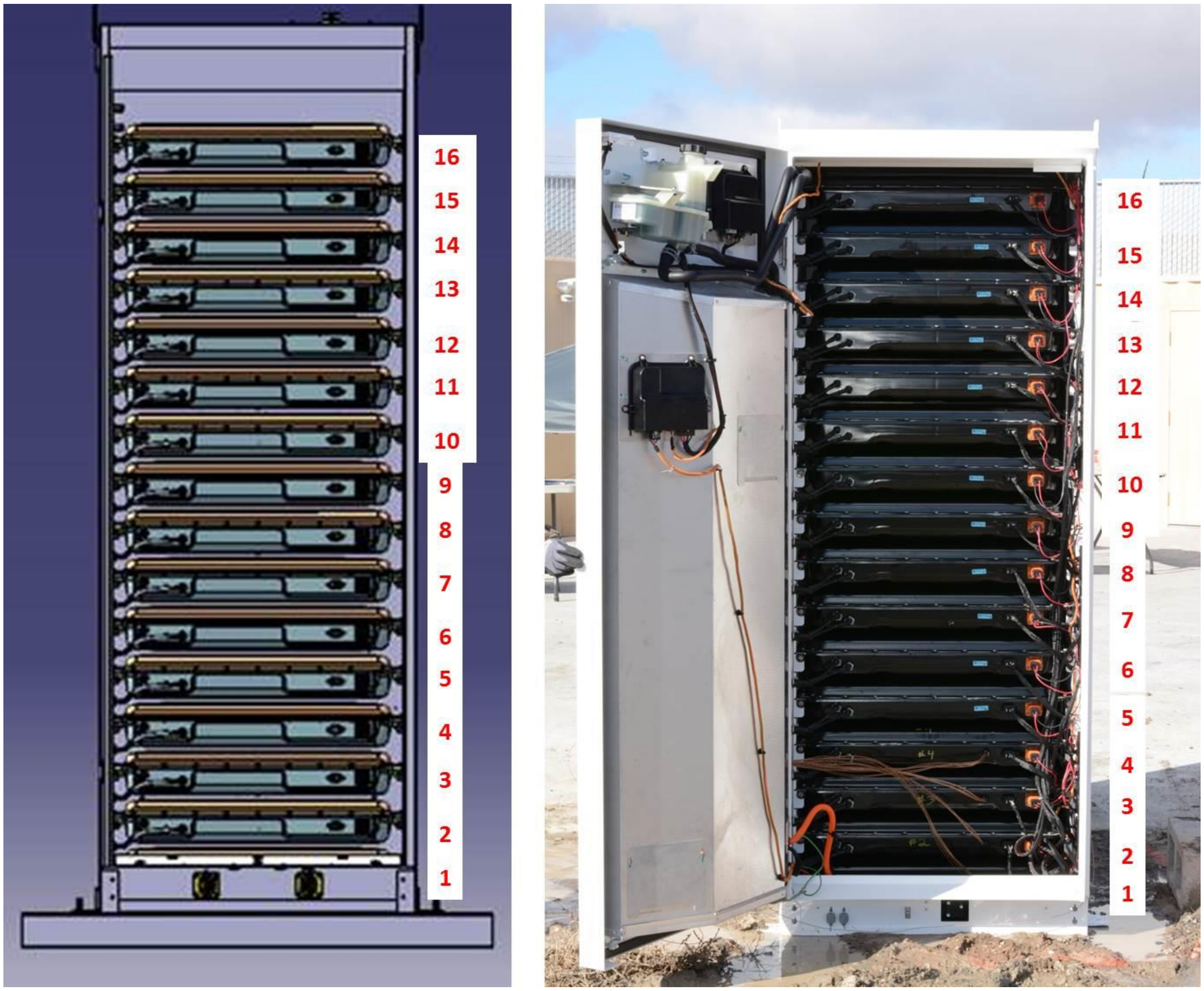

Figure 8 Powerpack illustration (left) and image (right); depicting the sixteen (16) energy storage pods installed within the cabinet and instrumented for testing

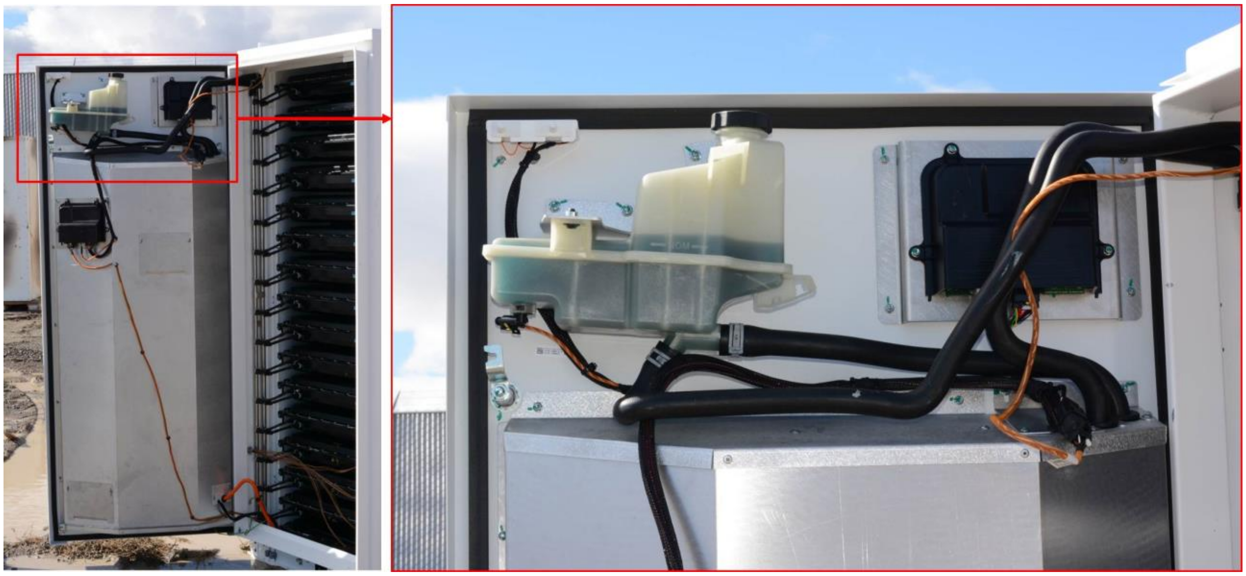

Figure 9 Powerpack thermal door (left) and close up of the refrigerant (right)

Figure 10 Illustration of the Powerpack exhaust vent (left) and an image of the vent at the top of the Powerpack (right)

4.3 ESS Safety Features

The Powerpack is listed to UL 1741, UL 1973, and IEC 62109. In addition, the Powerpack is designed to be compliant with UL 9540 and IEC 62619, currently under development by UL and IEC, respectively. UL1973, as described in Section 2.4.1, includes a number of construction requirements, performance tests, and production tests for stationary battery systems, including an external fire test and an internal fire test. The external fire test requires that the ESS not pose an explosion hazard if attacked by an external fire. The internal fire test demonstrates that a single battery cell failure within the center of the ESS battery pack will not result in a cascading thermal runaway of battery cells resulting in a propagating fire from the ESS and/or an explosion of the ESS.

Specific to the Powerpack design, each pod has a low voltage (approximately 50-volt) output that is later converted through power management electronics into the higher 400-volt Powerpack output. The energy storage pods are galvanically isolated and the 400-volt Powerpack output is only present when the Powerpack is in an active state and the power electronics are operational. Without active low voltage system electronics, because of the galvanic isolation, there is no electrical pathway from the live battery voltage to the exterior of a pod. As such, because of the design of the Powerpack, during charging or discharging, the cells are not at a high voltage. Each energy storage pod is encased inside a steel enclosure that prohibits any cell failure from projecting outside of pod. In addition, the pods are then enclosed within the steel Powerpack cabinet, which further reduces the possibility of projectiles from the unit. As described earlier, the energy storage pods are cooled by a thermal management system in the front door of the Powerpack cabinet that keeps the battery cells within safe operating temperatures. In the unlikely event of cell thermal runaway, the Powerpack has an engineered exhaust pathway, which directs runaway gas to a gas manifold that is directed out the top of the Powerpack. The Powerpack is designed to be installed side by side with multiple Powerpacks if additional storage capacity is desired. Clearance from the Powerpack is outlined in the manufacturer’s installation manual, which requires that combustibles be kept six feet from the front, six inches from the sides and back, and five feet from the top of the Powerpack.

5 Testing Setup

The full-scale fire tests were separated into two categories: (1) external ignition of the Powerpack and (2) internal ignition of the Powerpack, as described below. For both tests, the Powerpack battery packs were charged to a full 100% state of charge (SOC) prior to testing.

5.1 External Ignition Testing

The external ignition test exposed the Powerpack to a propane burner to simulate a fire scenario where the fire originates outside of the Powerpack.

5.1.1 ESS Positioning

The Powerpack was positioned on a noncombustible surface similar to its intended end use for an outdoor installation on a concrete pad, as shown in Figure 5. The test instrumentation, including thermocouples (TCs), heat flux gauges (HFGs), pressure transducers, gas sampling, data acquisition, weather meter, and cameras were positioned around the Powerpack as illustrated in Figure 11. In addition, a propane burner, further described in Section 5.1.2, was placed to the right side of the Powerpack, allowing for direct flame impingement on the exterior of the Powerpack cabinet.

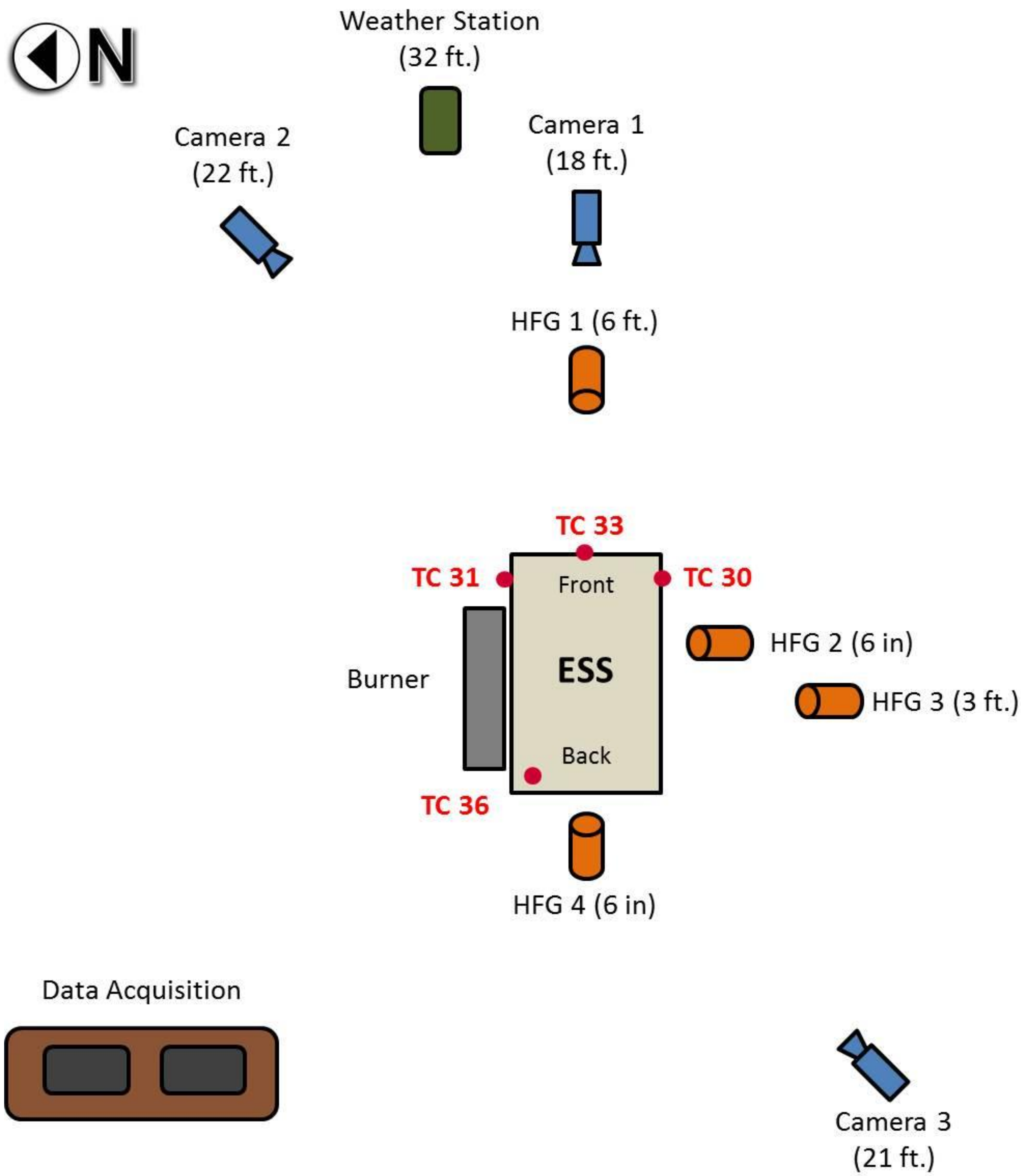

Figure 11 External fire test setup and instrumentation

5.1.2 Burner Description (Ignition Source)

The burner assembly consisted of three (3) drilled-pipe propane burners connected in parallel, as shown in Figure 12.

Each burner was 1.25 inches in diameter and 49 inches long and consisted of two rows of 2 mm orifices drilled at an angle 45 degrees apart. The orifices extended for 36 inches, spaced approximately 5 mm apart. The three burners were installed inside a five sided, 36 by 36 inch by 8 inch steel shell, with a steel mesh covering the opening to increase the amount of radiative heat load from the burner assembly to the exterior wall of the Powerpack enclosure. The burner assembly was positioned against the right side of the Powerpack cabinet to allow for direct flame impingement on the exterior of the unit, as shown in Figure 13. .

The flow of propane was monitored by a calibrated Omega FMA1845A mass flow meter, capable of measuring up to 1,000 liters per minute (lpm). The flow rate of propane was adjusted to provide an output of approximately 400 kW during the test.[81]

Figure 12 Burners utilized for testing

[81] HRR from the propane burners was determined based upon the flow rate of propane recorded by a mass flow meter during testing times the heat of combustion of propane.

Figure 13 Burner assembly and positioning

5.1.3 Temperature and Heat Flux Measurements

Temperatures were monitored with 1/8th-inch diameter bare bead Type K Chromel-Alumel thermocouples with an accuracy of ± 2.2°C or 0.75%, whichever is greater. Twenty-nine (29) thermocouples were placed on the exterior surfaces of the Powerpack, at selected battery pods inside the Powerpack, and within the Powerpack cabinet and exhaust manifold. Six (6) thermocouples were installed inside pods 1, 2, 3, and 4, for a total of 24 thermocouples monitoring the thermal runaway progression inside the battery pods, as shown in Figure 14. One (1) thermocouple was positioned inside the Powerpack cabinet exhaust manifold and another at the exhaust vent, as shown in Figure 15. Three (3) additional thermocouples were installed on the exterior surface of the Powerpack cabinet on the front, right side (burner side), and the left side of the Powerpack, as shown in Figure 11.

Heat fluxes were monitored with Schmidt-Boelter heat flux gauges capable of measuring up to 50 kW/m^2 ±3%. The heat flux gauge has a target 0.60 inches in diameter that is enclosed within a water cooled body two inches in diameter. Four (4) heat flux gauges were placed three feet above the ground at standoff distances of six feet in front of the Powerpack, six inches and three feet from the left side (opposite of the burner) of the Powerpack, and six inches from the back of the Powerpack, as shown in Figure 11. These distances are related to the clearance distances outlined in the Powerpack installation manual.

The location of each thermocouple and heat flux gauge is provided in Table 2 and Table 3.

Table 2 Summary of Thermocouple Locations for External Ignition Testing

TC	Measurement Location	TC	Measurement Location	TC	Measurement Location
0	Interior Pod #1	10	Interior Pod #2	20	Interior Pod #4
1	Interior Pod #1	11	Interior Pod #2	21	Interior Pod #4
2	Interior Pod #1	12	Interior Pod #3	22	Interior Pod #4
3	Interior Pod #1	13	Interior Pod #3	23	Interior Pod #4
4	Interior Pod #1	14	Interior Pod #3	30	Exterior Left
5	Interior Pod #1	15	Interior Pod #3	31	Exterior Right
6	Interior Pod #2	16	Interior Pod #3	32	Exhaust Manifold
7	Interior Pod #2	17	Interior Pod #3	33	Exterior Front
8	Interior Pod #2	18	Interior Pod #4	36	Exhaust Vent
9	Interior Pod #2	19	Interior Pod #4		

Table 3 Summary of Heat Flux Gauge Locations for External Ignition Testing

Heat Flux Gauge	Measurement Location	Heat Flux Gauge	Measurement Location
1	Front (6 ft)	3	Left (3 ft)
2	Left (6 in)	4	Back (6 in)

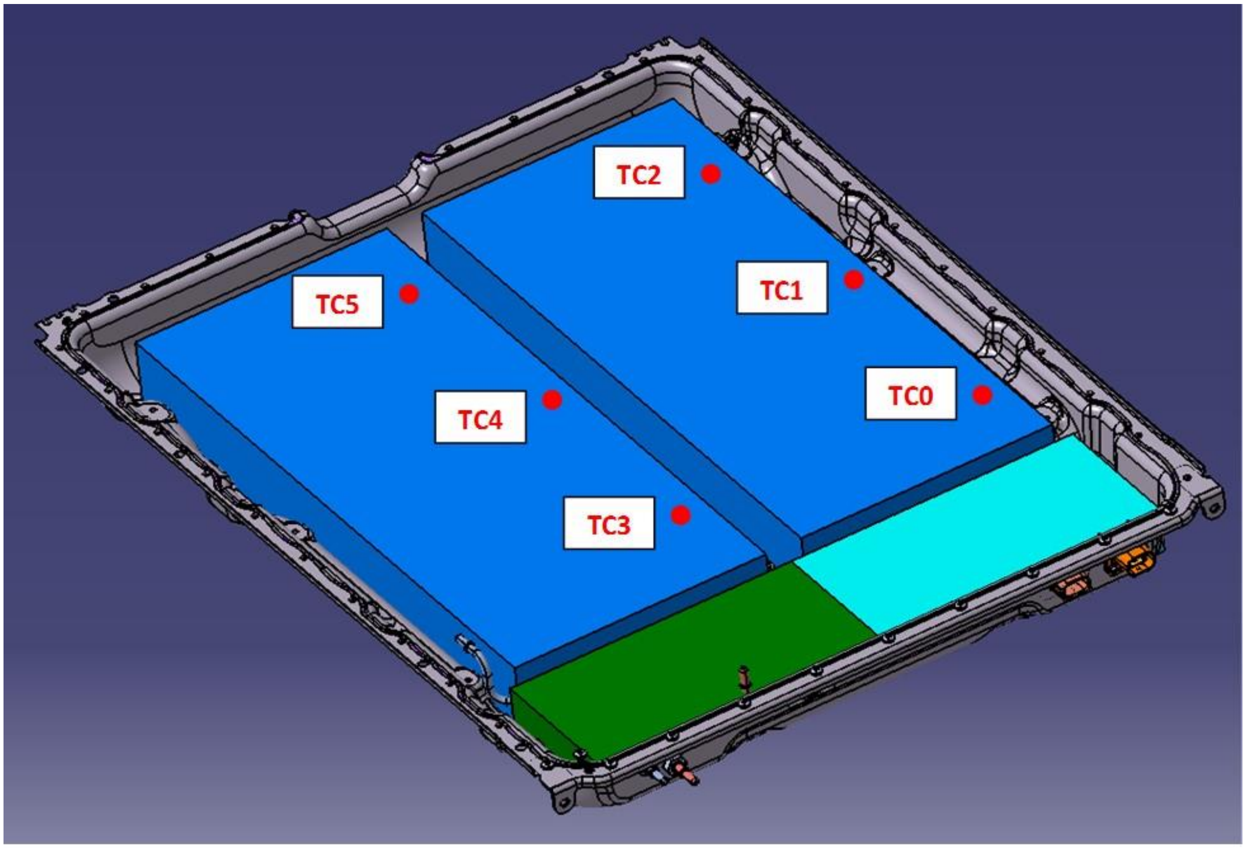

Figure 14 TC measurement locations within Pod 1; Pods 2 through 4 are similarly instrumented and labeled in the same numerical order

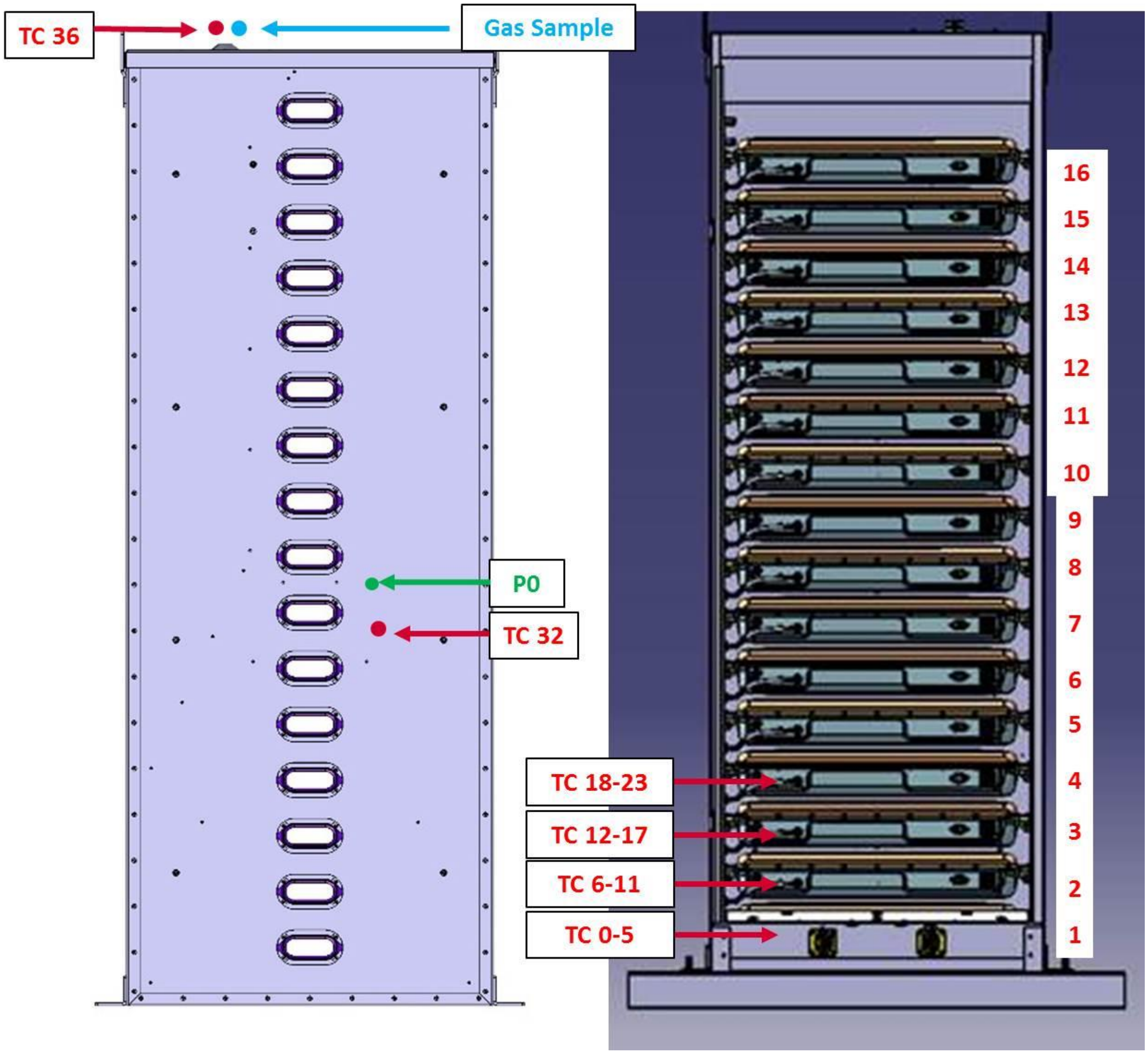

Figure 15 TC, gas sampling, and pressure measurement locations inside the Powerpack cabinet

5.1.4 Pressure Measurements

Pressures were monitored inside the Powerpack cabinet exhaust manifold using an Omega PX-309-015G5V pressure transducer capable of measuring up to 15 psi with an accuracy of ±0.25% full-scale. The transducer was positioned inside the Powerpack cabinet exhaust manifold to detect any overpressures inside the Powerpack cabinet during the test, as shown in Figure 15.

5.1.5 Products of Combustion Gas Sampling

Select products of combustion were monitored at the exhaust vent of the Powerpack cabinet as illustrated in Figure 15. The gas samples were analyzed with a MultiRAE Lite PGM-6208 and a calibrated PortaSens II portable gas leak detector; model C16, manufactured by Analytical Technology, Inc. Gases measured included CO, chlorine (Cl_2), methane (CH_4) (monitored by the MultiRAE Lite) and HF (monitored by the PortaSens II) at a range up to 2,000 ppm (±10 ppm), 50 ppm (±0.1 ppm), 0-100% volume/volume (±0.1%) and 100 ppm (±5%), respectively. Previous experience with Li-ion battery fires and information provided by Tesla focused the gas analysis to these four gasses during this test series. The two detectors were portable handheld units that contained their own built in pumps to draw a gas sample from the exhaust vent through tubing into the respective detector chamber.

5.1.6 Weather Meter

A Kestrel 4500 weather meter was utilized to monitor the ambient temperature, humidity, wind speed, and direction during testing. The Kestrel was positioned approximately 32 feet away from the Powerpack in an open space, away from any structures or objects that could affect the conditions being monitored, as illustrated in Figure 11.

5.1.7 Data Acquisition System

A National Instruments NI 9205 data acquisition unit was utilized to collect the heat flux and pressure measurements at a rate of 10 and 1,000 measurements per second, respectively, at a 16 bit resolution. A MeasurePoint DT9874 Isolation Temperature data acquisition unit was utilized to collect temperature measurements at a rate of 10 measurements per second at a 24 bit resolution. The gas analyzers and the weather meter utilized their own built in data acquisition and recording software to collect data.

5.1.8 Still Photography and High Definition Video

Still images and high definition videos were taken throughout the test. Video cameras were positioned around the Powerpack to get a 360-degree view of the Powerpack at all times, as illustrated in Figure 11. Still images were taken periodically during the test to capture the fire progression.

5.2 Internal Ignition Testing

The internal ignition test induced individual cells within the Powerpack to thermal runaway.

5.2.1 ESS Positioning

The Powerpack was positioned on a noncombustible surface similar to its intended end use installation on a concrete pad, as shown in Figure 5. The test instrumentation, including thermocouples (TCs), pressure transducers, gas sampling, data acquisition, weather meter, and cameras were positioned around the Powerpack as illustrated in Figure 16. In addition, heater cartridges utilized to force the individual batteries into thermal runaway, further described in Section 5.2.2, were positioned inside pod 6 (the initiator pod).

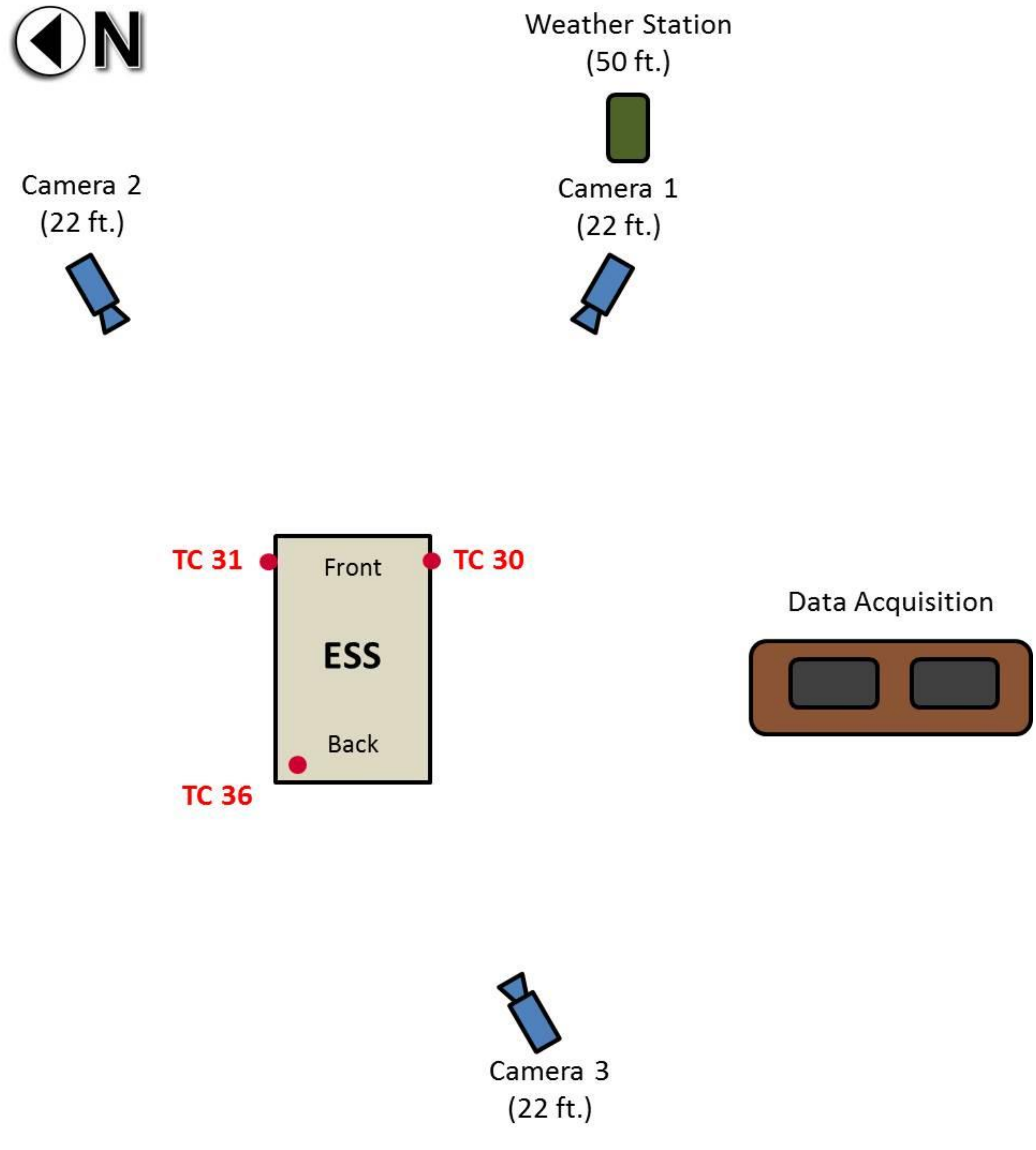

Figure 16 Internal ignition test setup and instrumentation

5.2.2 Internal Failure (Ignition Source)

The initiation method used in the internal ignition test consisted of using six (6) 1/8th-inch diameter 25-watt cartridge heaters, each placed in an interstitial space between the battery cells in Pod 6, as shown in Figure 18. All six heaters were clustered at the center of the module.

At the start of the test, current was applied to all six heaters simultaneously, resulting in an almost simultaneous thermal runaway of ten (10) cells. This method of inducing thermal runaway deliberately overwhelmed the passive propagation protection mechanisms of the Powerpack. After a minimum of ten cells had audibly undergone thermal runaway, the heaters were turned off.

5.2.3 Temperature Measurements

Temperatures were monitored with the same make and model 1/8th-inch diameter bare bead Type K Chromel-Alumel thermocouples as described in the external ignition testing. Thirty-seven (37) thermocouples were placed on the exterior surfaces of the Powerpack, at select battery pods inside the Powerpack, and within the Powerpack cabinet and exhaust manifold. Twelve (12) thermocouples were installed in the initiator pod (pod 6), as shown in Figure 17 and six (6) thermocouples were placed inside pod 5 and pod 7, the adjacent pods to the initiator pod, as shown in Figure 18 and Figure 19. In addition, two (2) thermocouples were placed on the top cover of pod 6, two (2) on the bottom of the cover of pod 7 and two (2) on the top of the cover of pod 5, to monitor the spread of fire, if any, outside of the initiator pod, as shown in Figure 20. Four (4) thermocouples were placed inside the Powerpack cabinet in the exhaust manifold and another thermocouple was placed at the exhaust vent, as shown in Figure 20. Two (2) final thermocouples were installed on the exterior surface of the Powerpack cabinet on the right and left sides of the Powerpack, as shown in Figure 16. The location of each thermocouple is provided in Table 4.

Table 4 Summary of Thermocouple Locations for Internal Ignition Testing

TC	Measurement Location	TC	Measurement Location	TC	Measurement Location
0	Interior Pod #6	12	Interior Pod #5	24	Pod #6 Cover
1	Interior Pod #6	13	Interior Pod #5	25	Pod #6 Cover
2	Interior Pod #6	14	Interior Pod #5	26	Pod #7 Cover
3	Interior Pod #6	15	Interior Pod #5	27	Pod #7 Cover
4	Interior Pod #6	16	Interior Pod #5	28	Pod #5 Cover
5	Interior Pod #6	17	Interior Pod #5	29	Pod #5 Cover
6	Interior Pod #6	18	Interior Pod #7	30	Exterior Left
7	Interior Pod #6	19	Interior Pod #7	31	Exterior Right
8	Interior Pod #6	20	Interior Pod #7	32	Exhaust Manifold
9	Interior Pod #6	21	Interior Pod #7	33	Exhaust Manifold
10	Interior Pod #6	22	Interior Pod #7	34	Exhaust Manifold
11	Interior Pod #6	23	Interior Pod #7	35	Exhaust Manifold
				36	Exhaust Vent

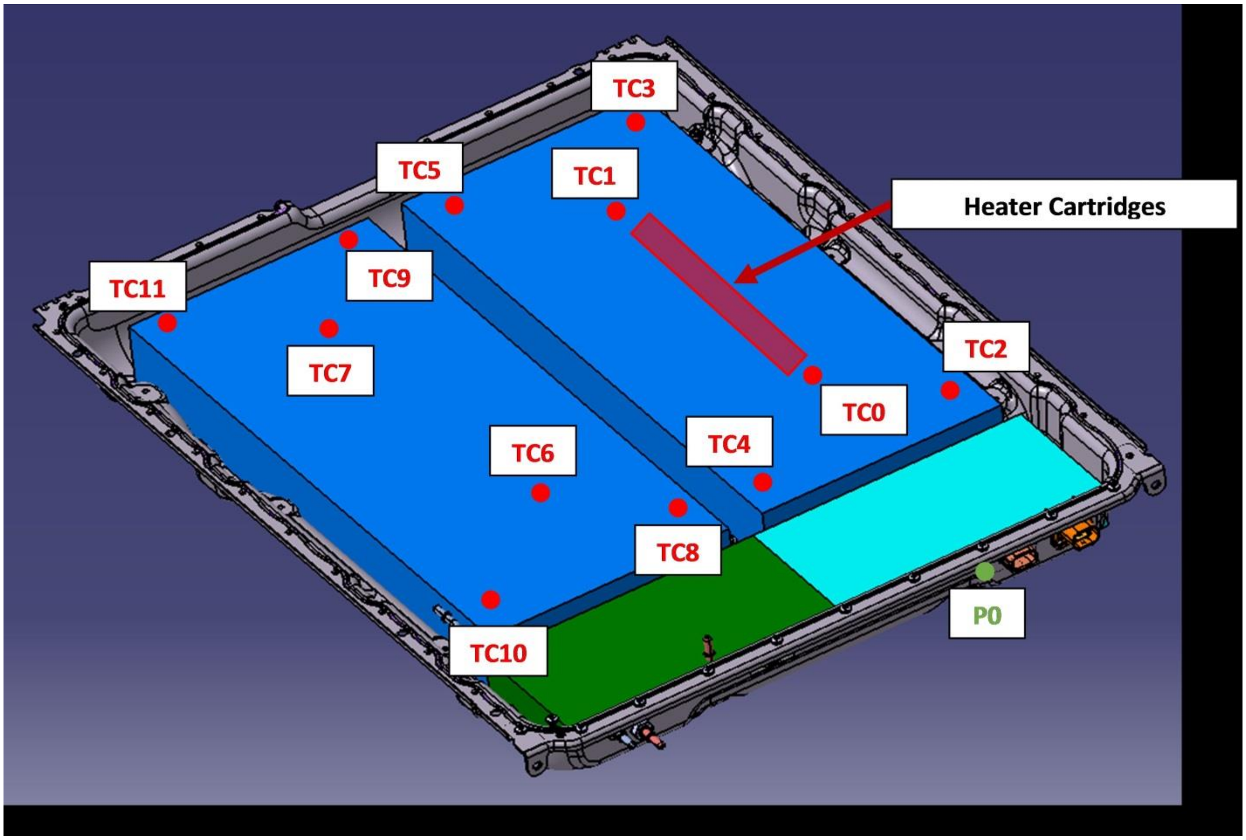

Figure 17 TC, pressure measurement and heater cartridge locations within Pod 6

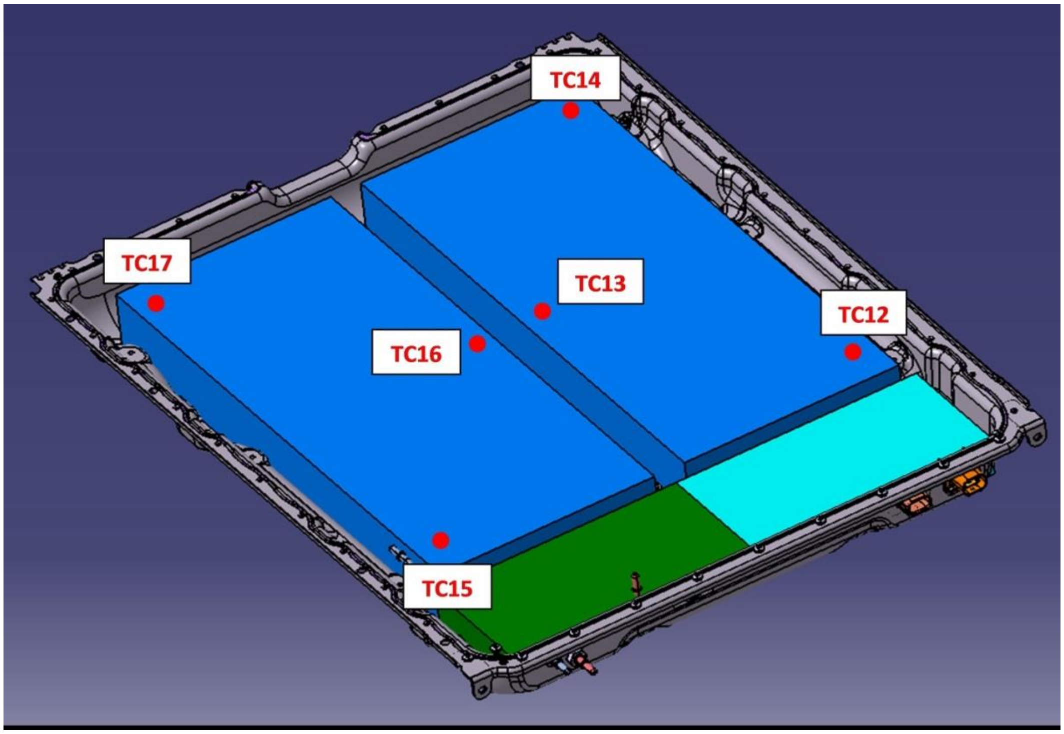

Figure 18 TC measurement locations within Pod 5

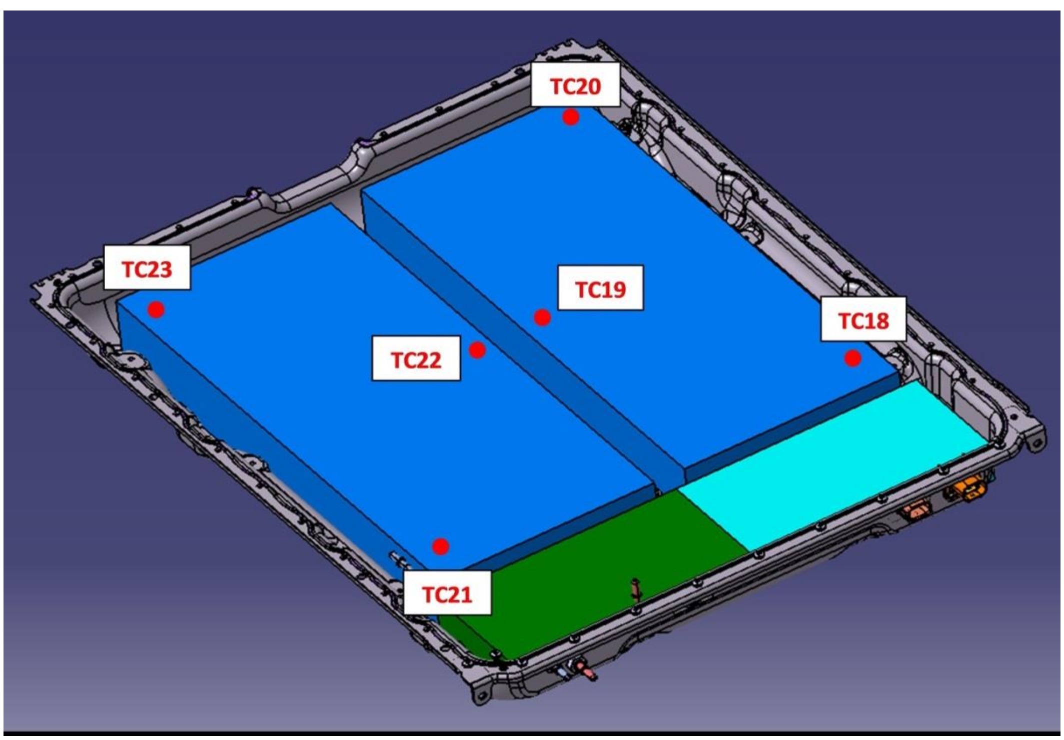

Figure 19 TC measurement locations within Pod 7

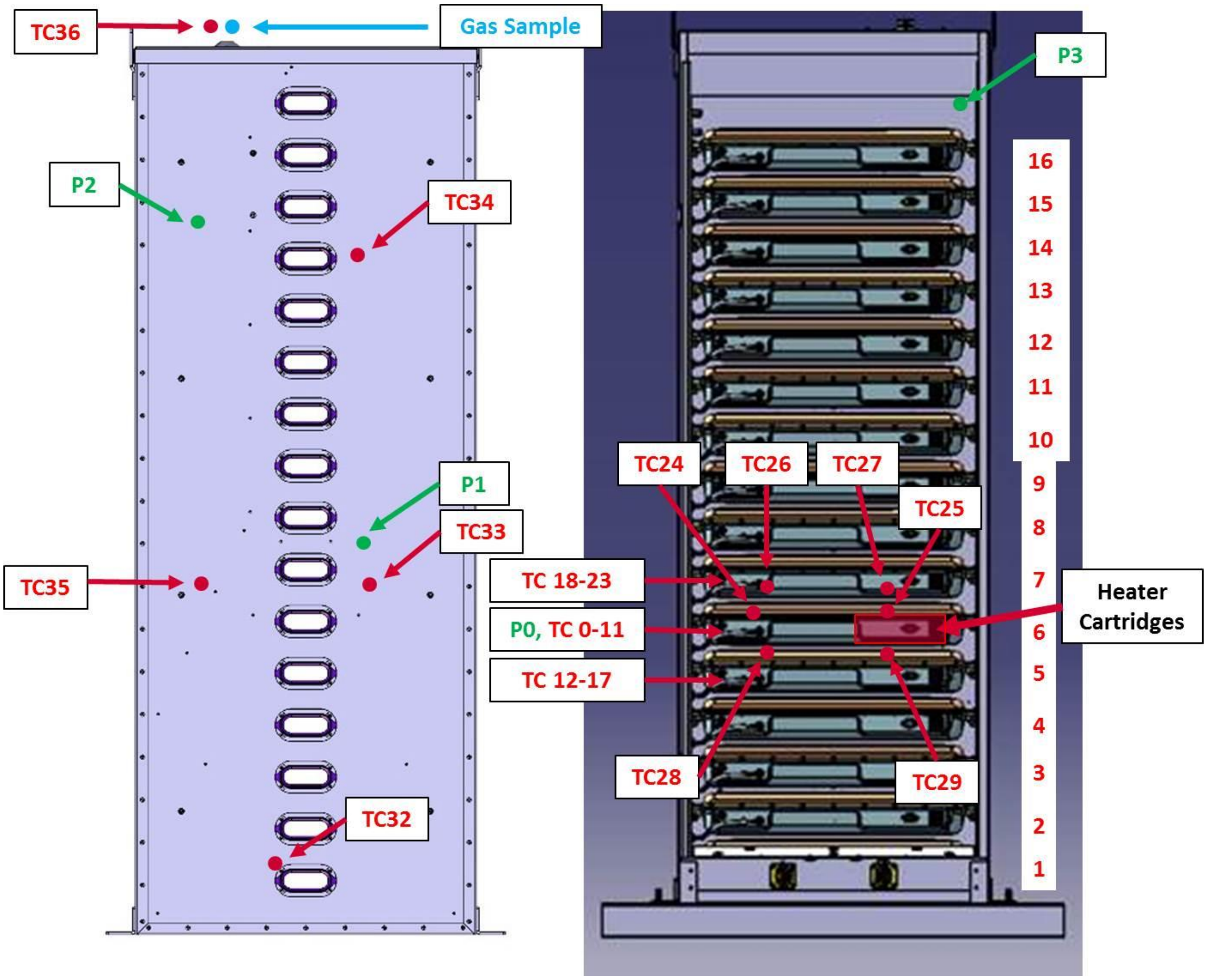

Figure 20 TC, gas sampling, and pressure measurement locations inside the Powerpack cabinet

5.2.4 Pressure Measurements

Pressures were monitored with the same make and model pressure transducers described in the external ignition testing. The transducers were positioned inside the Powerpack cabinet, as illustrated in Figure 20, as well as in the exhaust manifold and at the initiator pod to detect any overpressures in these locations during the test. The location of the pressure transducers is provided in Table 5.

Table 5 Summary of Pressure Measurement Locations for Internal Ignition Testing

Pressure Transducer	Measurement Location	Pressure Transducer	Measurement Location
0	Pod #6	2	Exhaust Manifold
1	Exhaust Manifold	3	Front Cabinet

5.2.5 Products of Combustion Gas Sampling

Select products of combustion were monitored at the exhaust vent of the Powerpack, as shown in Figure 20, with the same instrumentation as described in the external ignition test (see Section 5.1.5).

5.2.6 Weather Meter

Weather conditions were monitored with the same instrumentation as described in the external ignition test (see Section5.1.6). The weather meter was positioned approximately 50 feet away from the Powerpack, as shown in Figure 16.

5.2.7 Data Acquisition System

The same data acquisition unit described in the external ignition test (see Section 5.1.7) was utilized to collect the test data during the internal ignition test.

5.2.8 Still Photography and High Definition Video

Still images and high definition videos were recorded throughout the internal ignition test. Video cameras were positioned around the Powerpack to get a 360-degree view of the Powerpack at all times, as illustrated in Figure 16. Still images were taken periodically during the test to capture the test progression.

6 Test Results

Exponent witnessed the full-scale testing and reviewed the data collected to observe the behavior of the Powerpack when it is involved in a fire scenario. The tests were performed at the Tesla test facility on November 5, 2015, under the guidance and direction of FPRF and Exponent. Two tests were conducted; one external ignition test and one internal ignition test. For each test the Powerpack was positioned out in open air, on a noncombustible surface, as it would be typically installed in outdoor installations. The Powerpacks that were tested were 100 kWh units charged to 100% SOC, as described previously in Section 4.

6.1 External Ignition Testing

The external ignition test was conducted on November 5, 2015, at approximately 9:30 a.m. At the start of the test, the weather was overcast, with temperatures of approximately 35 °F and a relative humidity of approximately 65%. The wind was out of the west-southwest with a wind speed of 1.5 miles per hour (mph). Over the course of the three hour and forty-five minute test duration, the temperature slowly rose to 43 °F, the weather remained mostly overcast with no precipitation, the relative humidity dropped slowly to approximately 55%, and the wind remained calm out of the west or west-southwest, with speeds between 0 and 2.2 mph. The following sections summarize the data collected during the test.

6.1.1 Test Observations

Table 6 summarizes the key events observed by Exponent during the test. Images at significant test times are provided in Figure 21 through Figure 28. In general, the test demonstrated that an external heat source, such as a propane burner, could induce the Powerpack into thermal runaway and result in the ignition of electrolyte material and other combustibles within the Powerpack cabinet. Popping sounds from the interior of the Powerpack were heard throughout the test. White smoke was observed consistent with the release of flammable electrolyte material from individual cells. However, no violent projectiles, explosions, or bursts (other than an overpressure release of the thermal door refrigerant) were observed during the test while the Powerpack was exposed to the burners, while it was in a free burn state, or after flames were no longer visible. Flames remained mostly confined to the Powerpack itself. Weaker flames emanated from the exhaust vent of the Powerpack, the front thermal door grill, and around the front thermal door seal at varying times throughout the test.

Table 6 External Ignition Test: Key Observations

Time (hr:min:sec)	Event
- 0:03:00	Start data acquisition and video cameras
0:00:00	Ignite burner
0:35:12	First smoke (white and/or grey) observed from Powerpack
0:45:02	Pop sound heard from Powerpack cabinet (pops)
0:46:54	Sustained flames first observed at exhaust vent
0:47:09	Sustained flames first observed at back Powerpack panel
0:47:57	Sustained flames first observed at the front door
0:48:00	Steady pops heard from Powerpack starting at this time until 3:10:50 consistent with cell thermal runaway
1:00:00	Burners “OFF”, jet fire exiting exhaust vent, flames coming out of the front door grill
1:05:00 – 1:10:00	Material ejected from exhaust vent
1:08:00	Fire inside Powerpack only involving combustibles near the top; no burning of materials near the bottom of the Powerpack
1:11:00	Jet flame at exhaust vent weakens intermittently
1:14:30	Jet flame at exhaust vent increases in intensity
1:20:05	Overpressure sound consistent with refrigerant failure
1:27:00	Jet flame at exhaust vent weakens intermittently
1:27:45	Smoke from Powerpack turns darker
1:29:45	Flames inside Powerpack moving lower
1:32:05	Fire inside Powerpack intensifying
2:00:00	Fire inside Powerpack intensifying
2:30:00	Fire inside Powerpack steady
2:33:30	Fire inside Powerpack decreasing in intensity
3:00:00	Fire insides subsiding, weak flames observed out the front door and exhaust vent
3:10:50	Last pop heard from Powerpack
3:30:00	Fire continues to decrease in intensity
3:41:10	Last visible flame out
3:45:00	Cameras and data acquisition off

Figure 21 External test screenshot: start of test, burners “ON”

Figure 22 External test screenshot: test time = 1 hour, fire emanating from the front door and exhaust vent, pops consistent with battery cell thermal runaway heard steadily, burners turned “OFF”

Figure 23 External test screenshot: test time = 1 hour 30 minutes, flames at front door and exhaust vent intermittently decreasing in intensity

Figure 24 External test screenshot: test time = 2 hours, fire inside the Powerpack intensifying

Figure 25 External test screenshot: test time = 2 hours 30 minutes, fire inside the Powerpack intensifying

Figure 26 External test screenshot: test time = 3 hours, fire inside the Powerpack subsiding

Figure 27 External test screenshot: test time = 3 hours 30 minutes, fire inside the Powerpack burning itself out

Figure 28 External test screenshot: end of test, fire is out.

6.1.2 Temperatures and Heat Flux Measurements

Temperature and heat flux measurements were collected during the external ignition test and plots for each as a function of time are provided in Appendix A.

The maximum temperatures measured on the interior thermocouples installed within pods 1, 2, 3, and 4 were all consistent with direct flame contact, with temperatures in excess of 2,000 °F. The maximum temperatures measured on the exterior of the Powerpack cabinet were much lower. TC30, positioned on the left side of the Powerpack opposite of the burner, measured a maximum surface temperature of approximately 150 °F and TC33, positioned on the front door measured a maximum temperature of approximately 460 °F.

An analysis of the heat flux measurements yielded values inconsistent with observations of the test, the fire progression and its severity. As such, the data collected for heat fluxes was not considered in this fire hazard assessment.

6.1.3 Pressure Measurements

Pressure was monitored at the Powerpack exhaust manifold throughout the test and a plot of the pressure as a function of time is provided in Appendix B. No pressure build-up or release consistent with an overpressure event occurring inside the Powerpack cabinet was observed in the data or during the test.

6.1.4 Gas Sampling Measurements

Select products of combustion were monitored at the Powerpack exhaust vent throughout the test and a plot of CO and HF levels as a function of time are provided in Appendix C.

CO was first detected approximately 2.5 minutes after the burners were turned on at 10 ppm. The value steadily rose to its maximum value of 50 ppm approximately four minutes after the burners were turned on. The CO detected then slowly decreased to 0 ppm approximately 30 minutes after the burners were turned on and remained at 0 ppm for the remainder of the test. As such, the production of CO, as detected at the exhaust vent, only occurred while the external burner was on and CO was not detected while the Powerpack underwent self-sustaining combustion (i.e., the external burner was off).

No Cl_2 or CH_4 were detected in any quantities during the test.

HF was detected two minutes after the burners were turned on at 2 ppm. The value of HF steadily rose from 2 ppm to its maximum value of 100 ppm approximately 30 minutes after the burners were turned on. The maximum range of the HF detector was 100 ppm. All HF data after 30 minutes was "over range" of the HF detector, indicating HF levels were greater than 100 ppm for the duration of the test.

6.1.5 Post Test

Following the test, it was determined that all of the energy pods were damaged and there was no stranded energy within the Powerpack.

6.2 Internal Ignition Testing

The internal ignition test was conducted on November 5, 2015, at approximately 2:45 p.m. At the start of the test, the weather was sunny, with temperatures of approximately 49 °F and a relative humidity of approximately 32%. The wind was out of the west with a wind speed of 1.3 mph. Over the course of the hour and a half test duration, the temperatures fluctuated between approximately 45 and 54 °F, the weather remained mostly sunny with no precipitation, the relative humidity remained between 30 and 32%, and the wind remained calm out of the west or west-southwest, with speeds between 0.1 and 2.5 mph. The following sections summarize the data collected during the test.

6.2.1 Test Observations

Table 7 summarizes the key events observed during the test. Images at significant test times are provided in Figure 29 through Figure 31. In general, the internal ignition test demonstrated that heater cartridges installed within the battery pack could induce multiple battery cells into thermal runaway; however, the failures did not result in thermal runaway of battery cells outside of the initiator pod. Popping sounds from the interior of the Powerpack were heard sporadically throughout the test, and steadily for approximately 15 minutes. White smoke was observed consistent with the release of flammable electrolyte material from individual cells. However, no violent projectiles, explosions, or bursts were observed during the test. In addition, no flames or other signs of fire, other than smoke production, were observed. The event stopped on its own without thermal runaway occurring outside of the initiator pod.

Table 7 Internal Ignition Test: Key Observations

Time (hr:min:sec)	Event
- 0:01:30	Start data acquisition and video cameras
0:00:00	Turn on heater cartridges
0:12:35	Pop sound heard from Powerpack cabinet (pops)
0:15:10	First smoke (white and/or light grey) observed at exhaust vent
0:27:13	Light smoke continues at exhaust vent
0:29:35	Smoke at exhaust vent increasing
0:33:07	Pop heard from Powerpack cabinet
0:34:28	Smoke at exhaust vent increasing, getting darker (grey)
0:34:56	Pop heard from Powerpack cabinet
0:35:30	Smoke at exhaust vent increasing, getting darker (grey)
0:36:22	Steady pops heard from Powerpack starting at this time until 0:45:01 consistent with cell thermal runaway
0:38:34	Heater cartridges turned off.
0:45:01	Last pop heard from Powerpack
0:49:30	Smoke production at exhaust vent subsiding
1:00:00	Smoke production at exhaust vent subsiding
1:15:00	Smoke production at exhaust vent subsiding
1:30:00	Smoke production at exhaust vent barely visible, cameras and data acquisition turned off, test terminated

Figure 29 Internal test screenshot: start of test, heater cartridges “ON”

Figure 30 Internal test screenshot: peak smoke production approximately 35 to 40 minutes after the heater cartridges were turned “ON”

Figure 31 Internal test screenshot: end of test

6.2.2 Temperatures

Temperatures were collected during the internal ignition test and plots of the temperatures as a function of time are provided in Appendix D.

The maximum temperatures were measured in the initiator pod, Pod 6. In the module with the heater cartridge, maximum temperatures were recorded in excess of 2,000 °F for approximately two seconds at TC1 , which was one of the thermocouples installed closest to the heater cartridges and may have come in contact with a brief (2 second) flame as the cell underwent thermal runaway. The rest of the thermocouples within the module recorded temperatures up to approximately 1,550 °F. In the second module within pod 6, the temperatures were lower, with the maximum temperatures between 200 and 400 °F for the six thermocouples installed within that module. The maximum temperatures measured on the adjacent pods, pod 5 and pod 7, were much lower as well. Pod 5 recorded maximum temperatures between 80 and 125 °F and pod 7 recorded maximum temperatures between 80 and 180 °F. TC30, positioned on the left side of the Powerpack cabinet exterior, measured a maximum surface temperature of 70 °F and TC31, positioned on the right side of the Powerpack cabinet exterior, measured a maximum temperature of 60 °F.

6.2.3 Pressure Measurements

Pressure was monitored inside the Powerpack cabinet, exhaust manifold and at the initiator pod throughout the test and a plot of the pressure as a function of time is provided in Appendix E. No pressure build-up or release consistent with an overpressure event occurring inside the Powerpack cabinet or the initiator pod was observed in the data or during the test.

6.2.4 Gas Sampling Measurements

Select products of combustion were monitored at the Powerpack exhaust vent throughout the test and a plot of CO, CH_4, and HF levels as a function of time is provided in Appendix F.

CO was first detected approximately 10.5 minutes after the heaters were turned on at 10 ppm. The value steadily rose to its maximum value of 2,000 ppm approximately 12 minutes after the heaters were turned on, which is the maximum range for the CO detector. The value of CO remained at its maximum detection level of 2,000 ppm from the 12 minute mark until 63.5 minutes after the heaters were turned on. It then slowly decreased for the remaining 30 minutes of the test.

No Cl_2 was detected in any quantities during the test.

CH_4 was first detected approximately 12 minutes after the heaters were turned on. The detector measured CH_4 in percent volume fraction and steadily rose until approximately 36 minutes after the heaters were turned on, to a recorded a maximum percentage of 96.9. This time correlates with when the most cell runaways were observed in the test, as described in Section 6.2.1. It then slowly decreased for the remaining 54 minutes of the test.[82] The elevated CO and CH_4 levels detected after the heater cartridges were turned off and after thermal runaway of the cells had ceased indicates that CO and CH_4 can still be vented from the cells as they are cooling and obvious signs of thermal runaway (i.e., popping) are no longer observed.

HF was detected approximately 21 minutes after the heater cartridges were turned on at 1 ppm. The value of HF steadily rose from 1 ppm to its maximum value of 26 ppm approximately 46 minutes after the heater cartridges were turned on. The value plateaued at 26 ppm for 2 additional minutes (minute 47 and 48), then steadily declined back down to a value of 2 ppm by the end of the test.

6.2.5 Post Test

Following the test, it was determined that only one of the energy pods (the initiator pod) was damaged. The other 15 pods remained operational and had a full SOC. The energy pods were discharged and the Powerpack was recycled.

[82] During thermal runaway of the battery cell methane can be released. During the external ignition test no methane was detected at the exhaust vent, likely a result of the fire inside the ESS igniting any off gassing methane from the cells. However during the internal ignition test, no flames were observed and the released methane vented into the exhaust manifold and out the exhaust vent. Methane was also detected in previous testing programs, such as during the FAA's fire tests of cylindrical battery cells.

7 Key Findings

The following section is a discussion of the data and observations collected during the literature review and full-scale testing and supplements the presentation of the data in Sections 2 and 6.

7.1 Literature Review Summary

Li-ion ESSs are becoming more popular and are posed to be installed in many occupancies across the country, including commercial and residential buildings. However, little public knowledge is known about the fire hazards they pose to those buildings and their occupants.

7.1.1 Electrical, Fire, and Building Codes

Several gaps were identified in a review of electrical, fire, and building codes typically adopted in the United States as they relate to ESSs. These gaps are predominantly related to sections of the codes categorizing battery systems based on the volume of liquid electrolyte, which is not appropriate for assessing Li-ion ESS hazards. In addition, NFPA 1 provides contradictory guidance regarding thermal runaway protection for Li-ion battery systems, while the IFC does not require it at all. These gaps can be corrected with changes to the sections identified at the ICC code action hearings and NFPA technical committee meetings, some of which are currently being undertaken. In addition, the next edition of the NEC, the 2017 edition, is proposed to have a new article (Article 706) dedicated to ESSs. This addition should further assist installers, AHJs, and manufacturers with navigating the electrical installation requirements for these systems. However, it should also be noted that guidance for Li-ion battery system installations is currently within the codes and has been since 2006, most notably Section 608 of the IFC and since 2009, Chapter 52 of NFPA 1. Many of the concerns over the installation of battery systems could be addressed by local jurisdictions adopting more current editions of the ICC codes.

7.1.2 Design Standards

The ESS assessed in this testing program was listed to UL 1741, UL 1973, and IEC 62109 and was designed to be compliant with UL 9540 and IEC 62619, currently under development. UL

1973 requires stationary battery systems to meet two fire tests: one originating internally at the battery cell level and one externally by means of a hydrocarbon pool fire.

7.1.3 ESS Fires

Real world experience with Li-ion ESS fire incidents are limited, likely stemming from the early stage of adoption that these systems are currently in. Only one case was identified in the public records where a Li-ion ESS was involved in a fire; however, the details of that fire are not known, as requests for more information for public sources have not yielded any additional details. Previous research on other large format Li-ion batteries had demonstrated that the batteries did not significantly add to the HRR of the fire, that the fires can be extinguished with large amounts of water, the batteries can pose a projectile hazard when designed with cylindrical 18650 cells, but do not pose that hazard with polymer or pouch style cells, that toxic compounds such as CO_2, NO_x, HCN, HCl, CO, and HF can be produced during the fires, water samples collected after extinguishing Li-ion battery fires can contain concentrations of fluoride and chloride, and that no electrical hazards exist for personnel suppressing a battery fire from current leakage through the hose stream provided they are standing at specified standoff distances.

7.1.4 Knowledge Gaps

As stated in Section 2, the following gaps in the knowledge base for commercial and residential Li-ion ESSs have been identified:

1. No public fire test data demonstrating the fire behavior of ESSs.
2. Limited public fire test data related to large format battery packs with cylindrical design utilized either in vehicles or storage systems.
3. No fire test data or real world fire incidents involving residential or commercial Li-ion ESSs illustrating the hazards (projectiles, heat release, toxic gas production) to first responders and/or the best practices for fire department operations.
4. No Li-ion ESS guidance in the IRC.
5. Limited real world fire incidents involving large-scale (grid size) ESSs.

6. Some sections of the IBC, IFC, and NFPA 1 are confusing, as only the volume of the electrolyte (a requirement for older battery chemistries such as lead acid) and not the weight of the Li-ion battery system, is used as a threshold for when certain building or fire code requirements are necessary. In addition, other agencies, such as the United Nations and DOT, have other methods for defining and categorizing batteries. Many of these code sections are presently being revised and could be addressed by the next published code set.

7. NFPA 1 provides contradictory guidance regarding thermal runway protection for Li-ion battery systems, while the IFC does not require thermal runaway protection for Li-ion battery systems at all. Many of these code sections are presently being addressed and could be resolved by the next published code set.

8. No post-fire incident response and recovery (i.e., overhaul) procedures.

9. No stationary battery system or ESS fire reporting code in NFIRS to assist in analyzing fire incidents and differentiate battery systems from household batteries.

7.2 Test Summary

The following sections highlight the key findings from the full-scale fire tests.

7.2.1 Overall Test Observations

A 400 kW propane burner impinging directly on the side of the Powerpack for approximately 60 minutes was required to achieve self-sustaining thermal runaway in the Powerpack battery pack and ignite interior components within the Powerpack cabinet. The test had a duration of approximately 3 hours and 45 minutes until the fire burned itself out. Flames were observed breaching the cabinet at the front door of the Powerpack and out the top of the Powerpack at the exhaust vent. No projectiles or explosions were observed at any time during either test.

During the internal ignition test, individual battery cells were forced into thermal runaway; however, no flames were observed at any time. Smoke was observed emanating from the Powerpack at the exhaust vent, however, within 1 hour and 30 minutes the smoke had dissipated and the thermal event was over. The Powerpack was designed to stop a single battery cell failure from cascading into a series of thermal runaways of adjacent battery cells, a design safety feature deliberately overwhelmed in this test through the use of multiple heater cartridges. However, the event was still contained within the Powerpack and did not propagate outside of the initial pod where the heaters were installed.

7.2.2 Flame Spread Hazards

Temperature measurements in the external ignition test demonstrated that a fire inside the Powerpack can reach elevated temperatures in excess of 2,000 °F. Exterior temperatures at the Powerpack cabinet were much lower and would not pose a fire spread hazard if the manufacturer recommended clearance distances to combustibles, as specified by the installation manual, are followed. Flames did breach the front door; however, the recommended clearance distance of six feet would likely eliminate any direct flame spread from the front door to nearby combustibles. Given that the unit tested can be installed outdoors, wind conditions could affect any flames emanating from the Powerpack. During these tests, the wind was calm with speeds at or less than 2 mph. As such, the hazard that a high wind scenario could inflict on the flame spread was not directly assessed during these two tests and may warrant further investigation. In addition, a standalone Powerpack was tested in this test program, not a large installation with many Powerpacks installed in an array. As such, the effects, if any, of additional Powerpacks installed within close proximity to one another was not directly assessed during these two tests and may warrant further investigation.

Flames several feet high were observed from the exhaust vent at the top of the Powerpack. The installation manual recommends at least five feet of clearance above the Powerpack. This clearance may not be sufficient if combustible materials are installed above the Powerpack, such as a building canopy or awning. It is recommended that this clearance distance be evaluated when a system is being installed, especially if the installed system is adjacent to a building or structure that has or could have combustibles installed above the Powerpack.

During the internal ignition test the temperatures recorded were much lower, with exterior cabinet surface temperatures only slightly higher than ambient and no observed flames emanating from inside the Powerpack. Based on this test, the flame spread hazard from an internal cell failure for combustibles positioned at the recommended clearance distances away from the Powerpack is negligible.

7.2.3 Products of Combustion Hazards

The release of HF during Li-ion fires is well known and HF was detected in both fire tests. The maximum range for the portable detector utilized in testing was 100 ppm, which was exceeded during the external ignition test after 30 minutes of burner exposure to the Powerpack. During the internal ignition test, the maximum recorded HF was 26 ppm, as less battery cells were involved compared to the external ignition test. Both of these measurements are greater than the recommended exposure levels over an 8 hour period as specified by the Occupational Safety & Health Administration (OSHA). It is recommended that first responders don typical firefighting self-contained breathing apparatus (SCBA) equipment when responding to an outdoor Li-ion battery fire. CO was also detected in both fire tests, though more significantly in the internal ignition fire test. Based on these test results, if installed indoors, additional ventilation of the Powerpack and/or for the room in which it is installed may be required. In addition, this test series only assessed select products of combustion produced during the Powerpack fires, namely HF. Additional testing accounting for other toxic products of combustion may warrant further investigation.

8 Recommendations and Future Work

The following recommendations and possible future work are suggested (Phase II) to further identify and understand the fire hazards of Li-ion ESSs:

- Research studying first responder tactics and suppression for Li-ion ESS fires.
- Research studying post fire incident response and recovery (i.e., overhaul) procedures.
- Heat release rate testing of ESSs.
- Testing to study what effect, if any, severe wind conditions may have on the spread of flames from one ESS to another or to other nearby combustibles.
- Testing to study what effect, if any, an array of ESSs installed within close proximity to one another would have on the spread of flames from one ESS to another or to other nearby combustibles.
- Testing of ESSs inside a compartment to study what effect, if any, a room will have on the fire behavior and potential toxic gas hazards within an enclosure.
- Testing to study different ESS manufacturers' products, battery chemistries, and/or sizes under similar conditions to verify the performance of other ESSs under these fire conditions.
- The addition of a stationary battery or ESS code in NFIRS such that fires in these systems can be differentiated from other battery fires, such as household batteries.
- Resolve the conflicting code sections relating to ESSs.

9 Acknowledgements

The authors would like to thank Tesla for donating the Powerpacks and for their significant efforts during this project.

The authors further thank Kathleen Almand, Executive Director of FPRF, Daniel Gorham, Research Project Manager, and everyone on the FPRF Advisory Panel.

Appendix A: External Ignition Test: Temperature and Heat Flux Plots

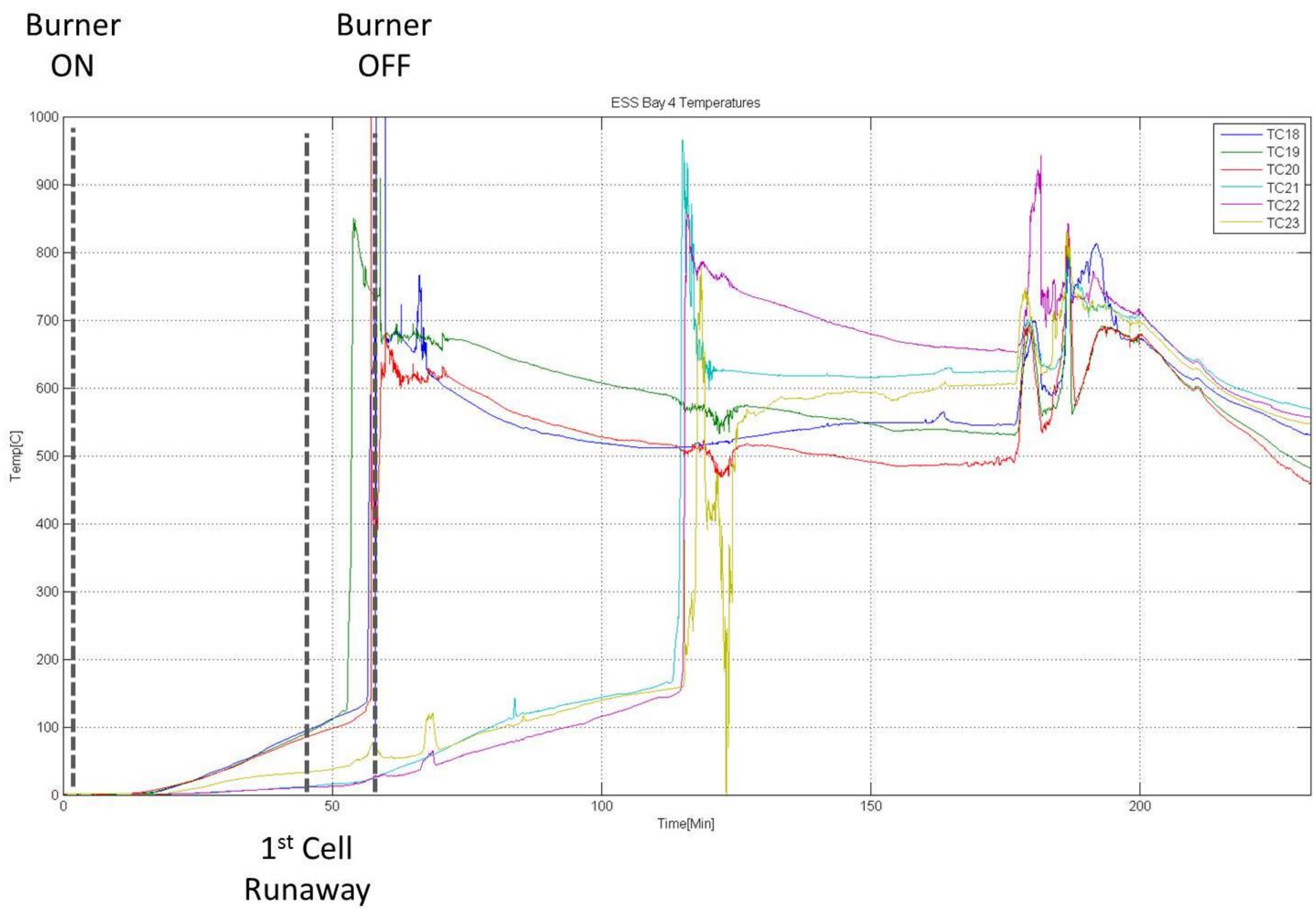

Figure 32 Powerpack Pod 4 temperatures (noise observed in the data is consistent with electrical interference that occurs during voltage leakage from the damaged batteries after thermal runaway)

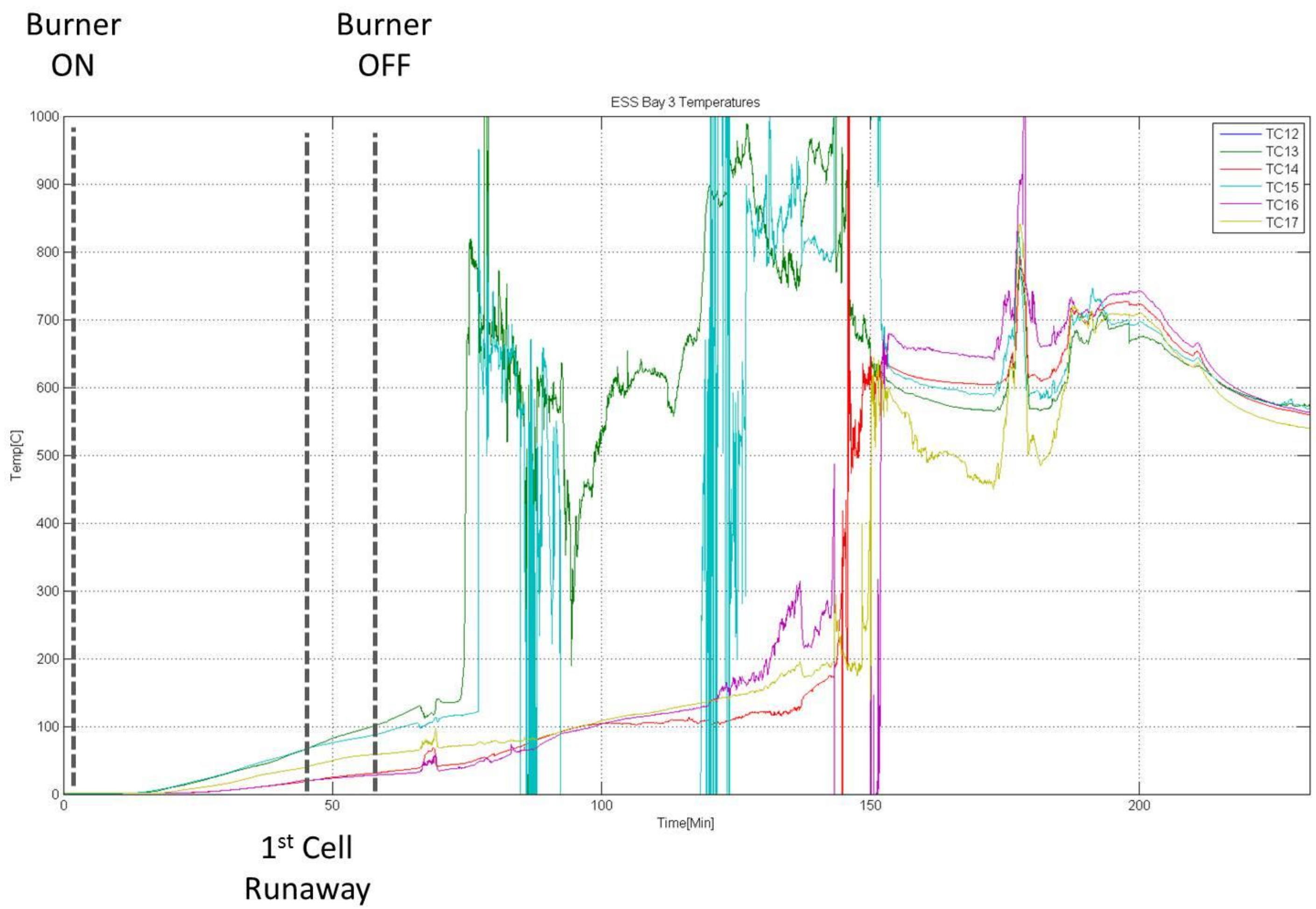

Figure 33 Powerpack Pod 3 temperatures (noise observed in the data is consistent with electrical interference that occurs during voltage leakage from the damaged batteries after thermal runaway)

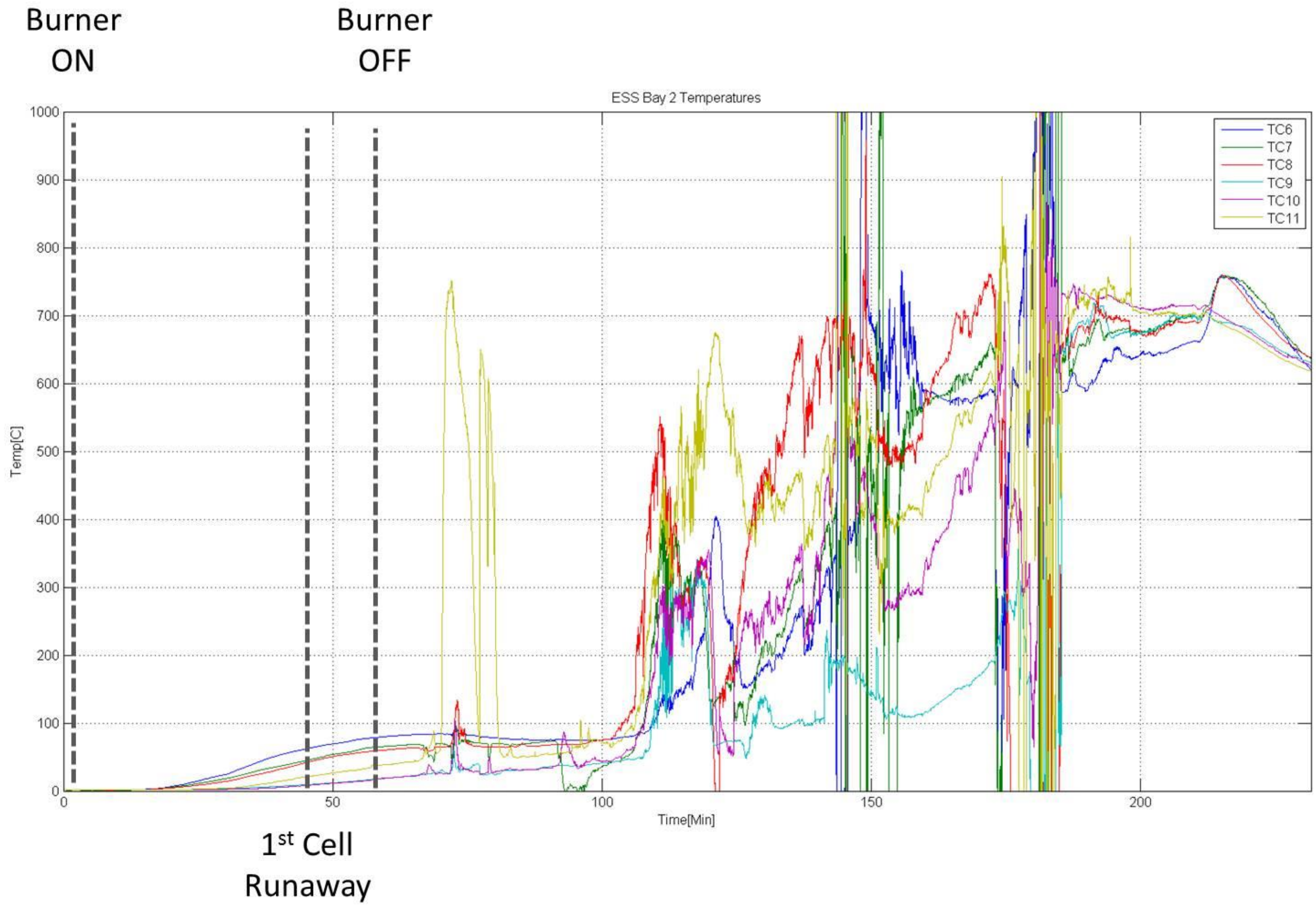

Figure 34 Powerpack Pod 2 temperatures (noise observed in the data is consistent with electrical interference that occurs during voltage leakage from the damaged batteries after thermal runaway)

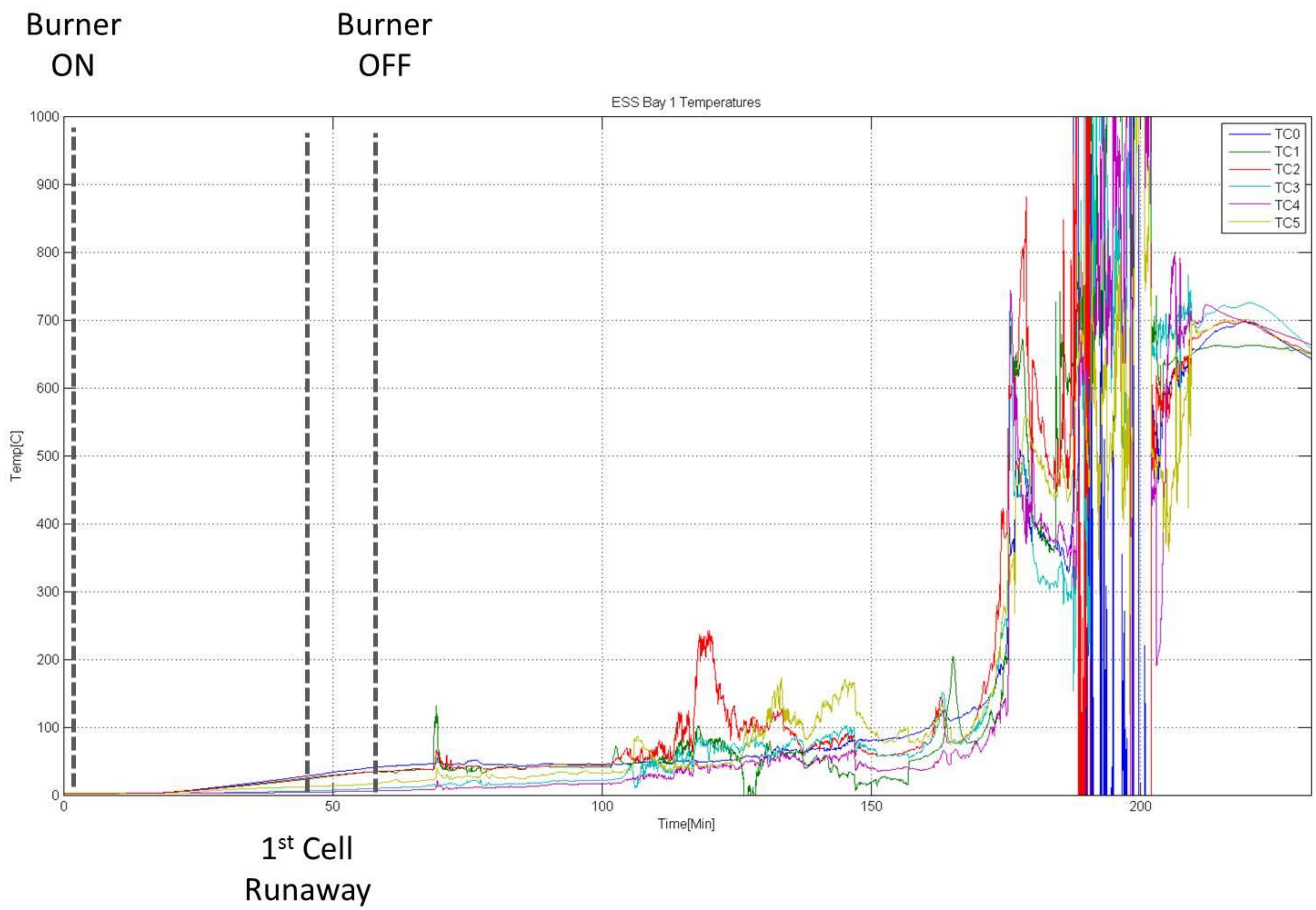

Figure 35 Powerpack Pod 1 temperatures (noise observed in the data is consistent with electrical interference that occurs during voltage leakage from the damaged batteries after thermal runaway)

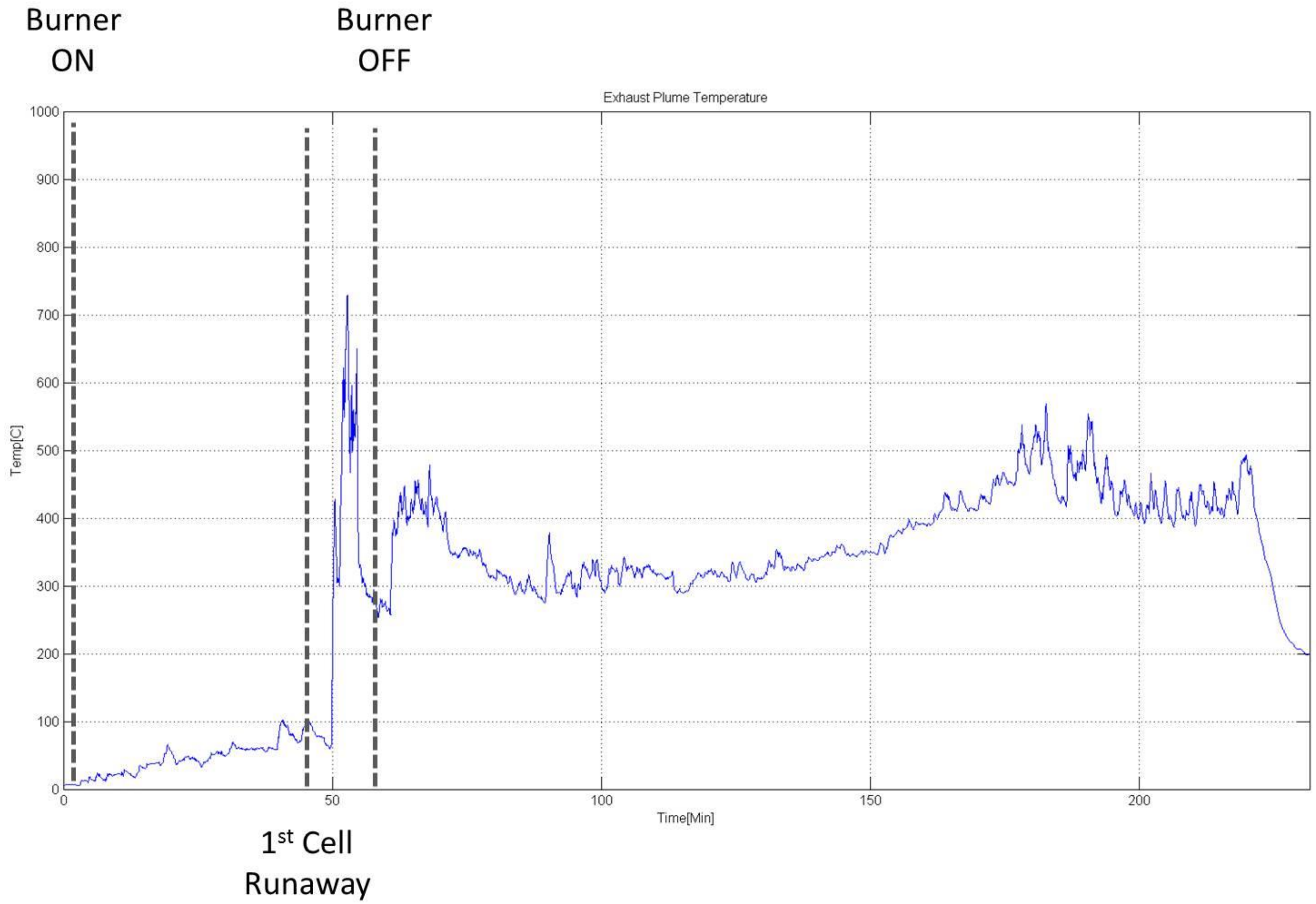

Figure 36 Powerpack exhaust vent temperature

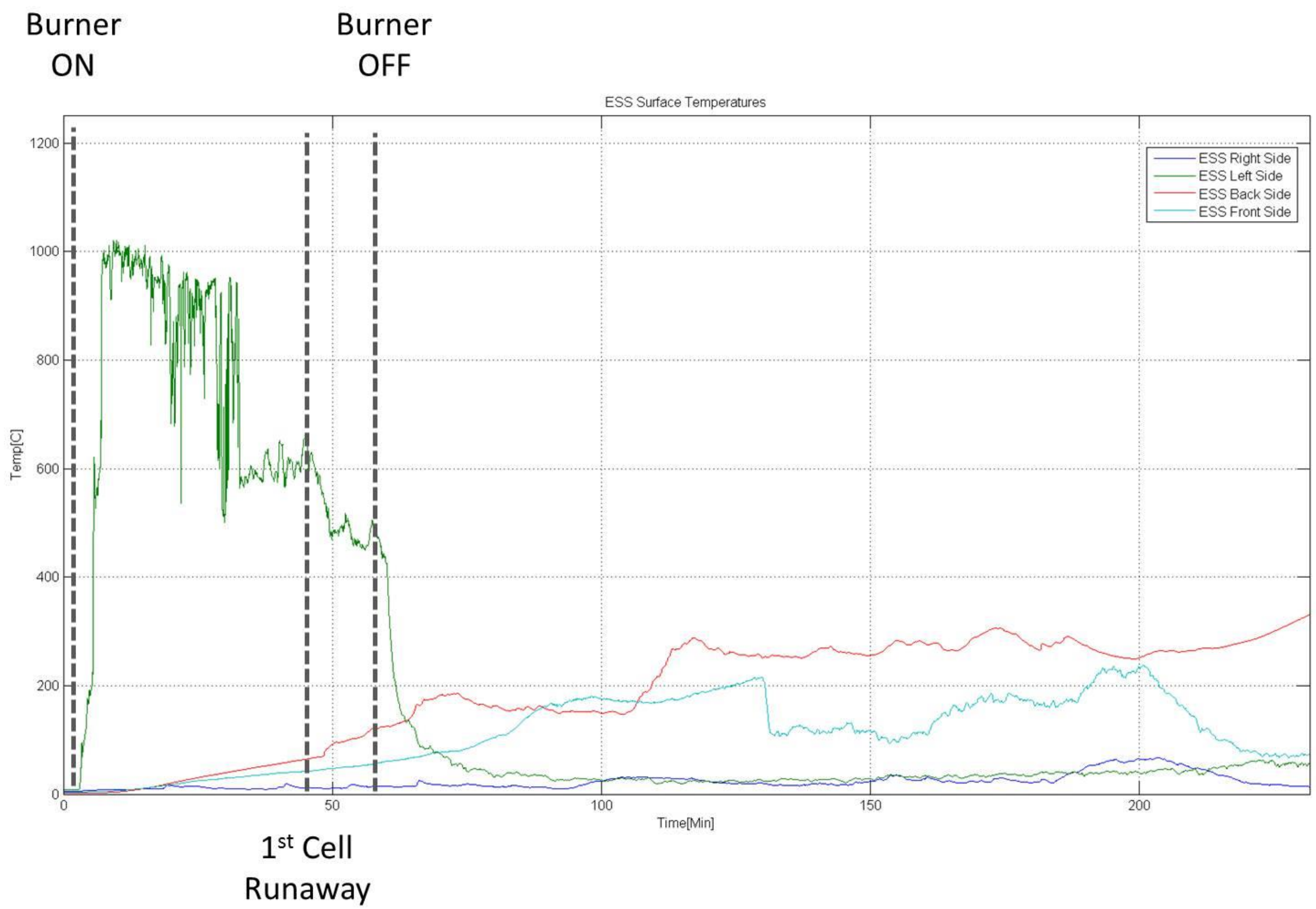

Figure 37 Powerpack external surface temperatures

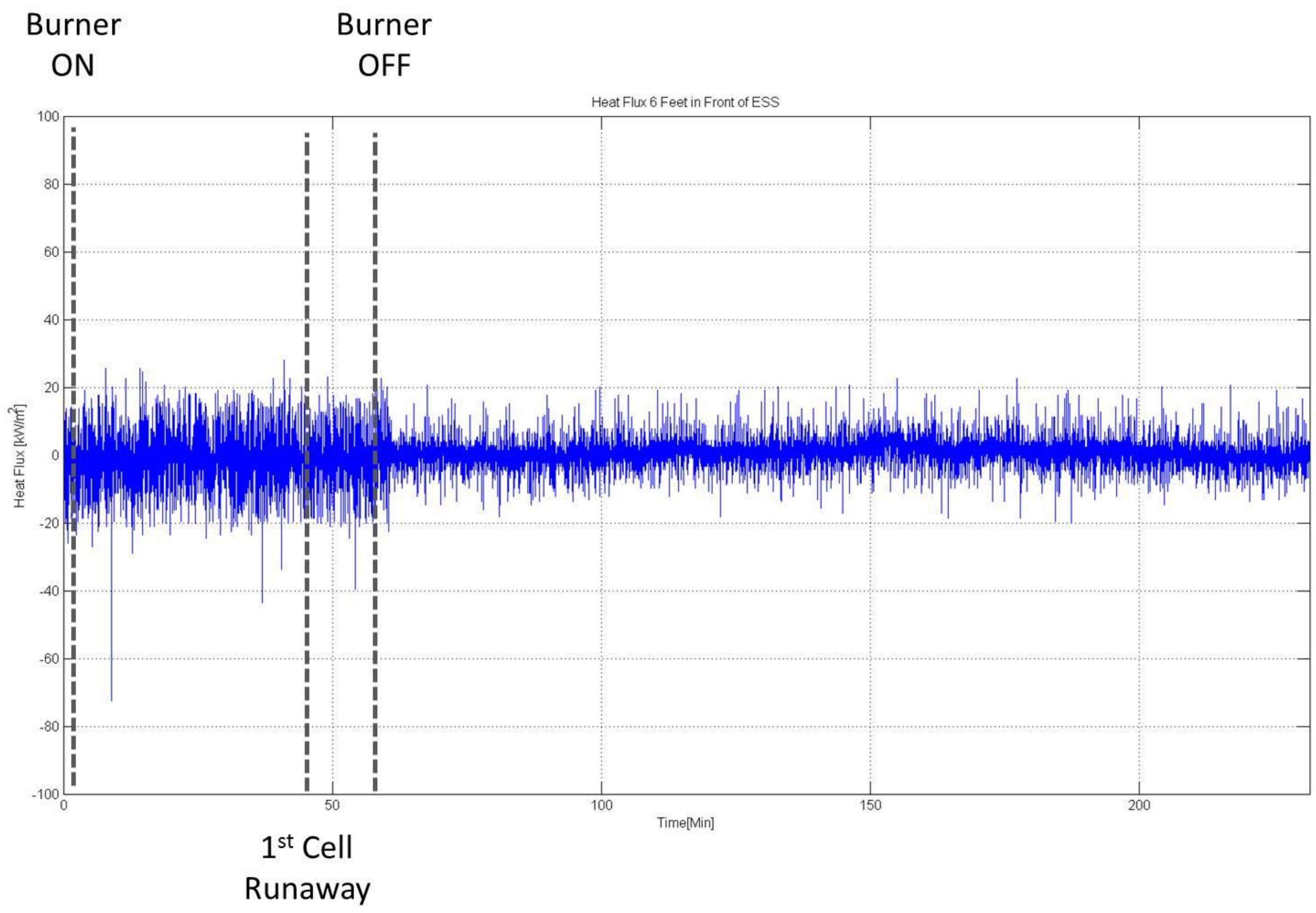

Figure 38 Heat flux measurements at HFG1, 6 feet from the front of the Powerpack

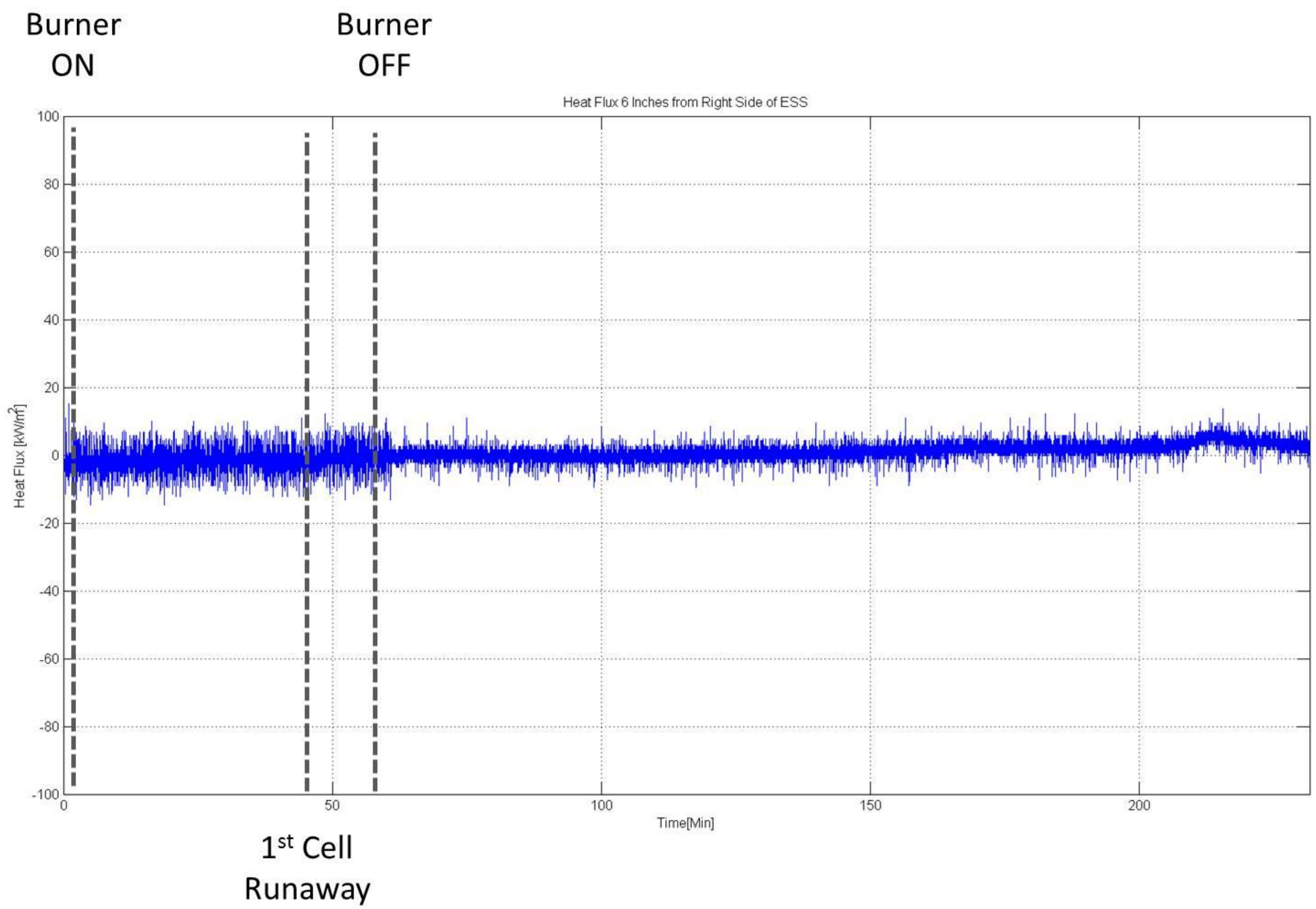

Figure 39 Heat flux measurements at HFG2, 6 inches from the side of the Powerpack

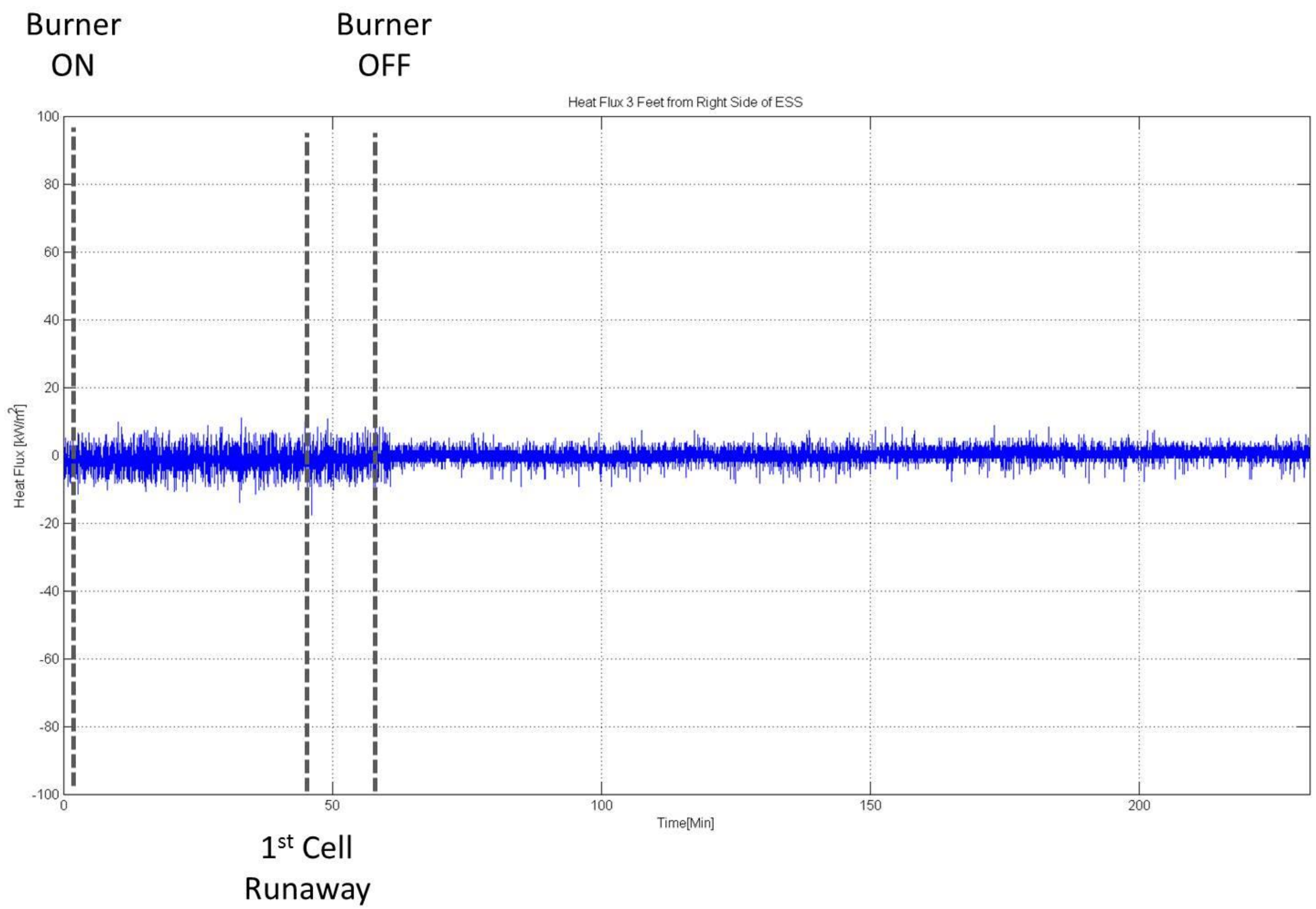

Figure 40 Heat flux measurements at HFG3, 3 feet from the back of the Powerpack

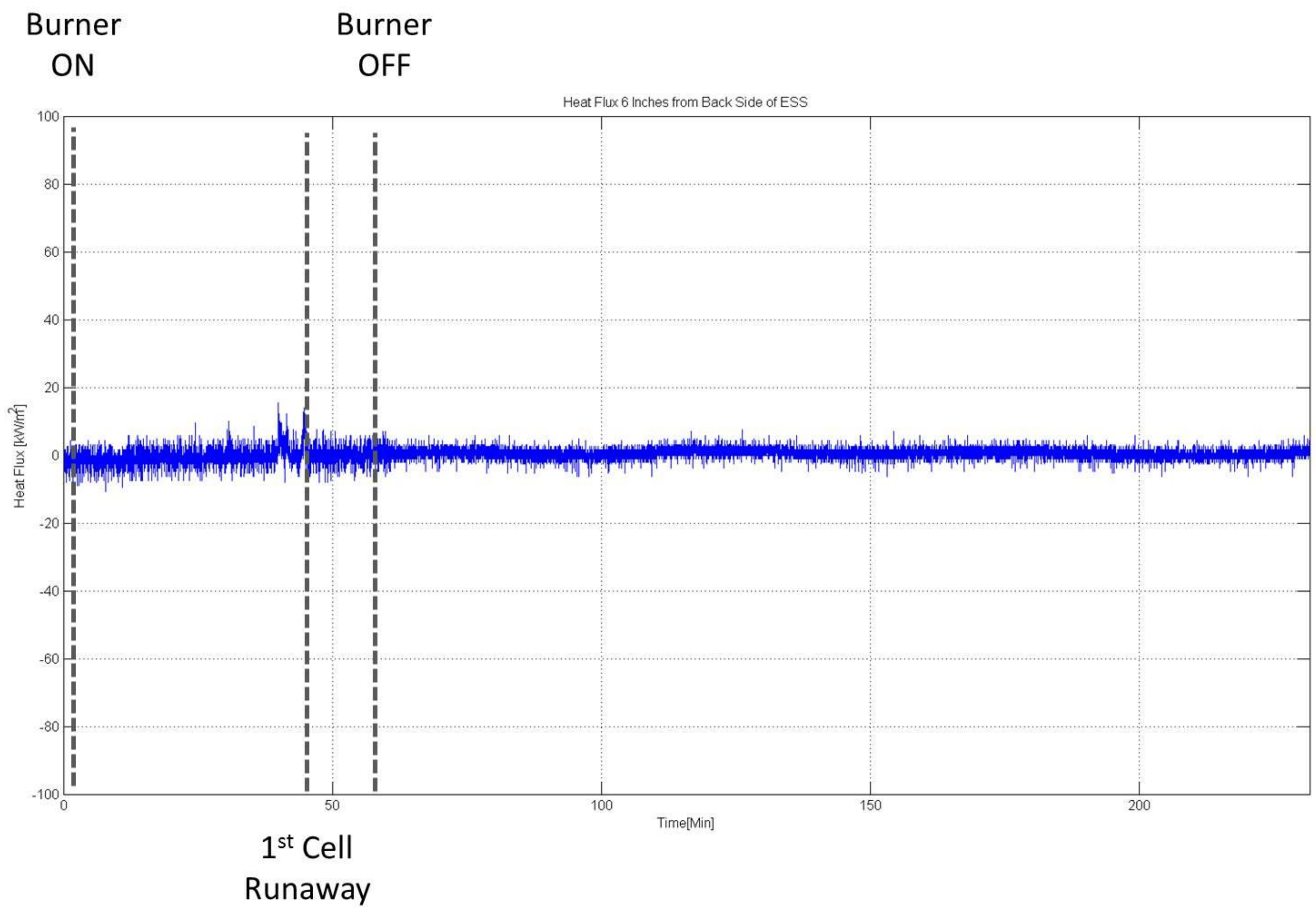

Figure 41 Heat flux measurements at HFG4, 6 inches from the side of the Powerpack

Appendix B: External Ignition Test: Pressure Plot

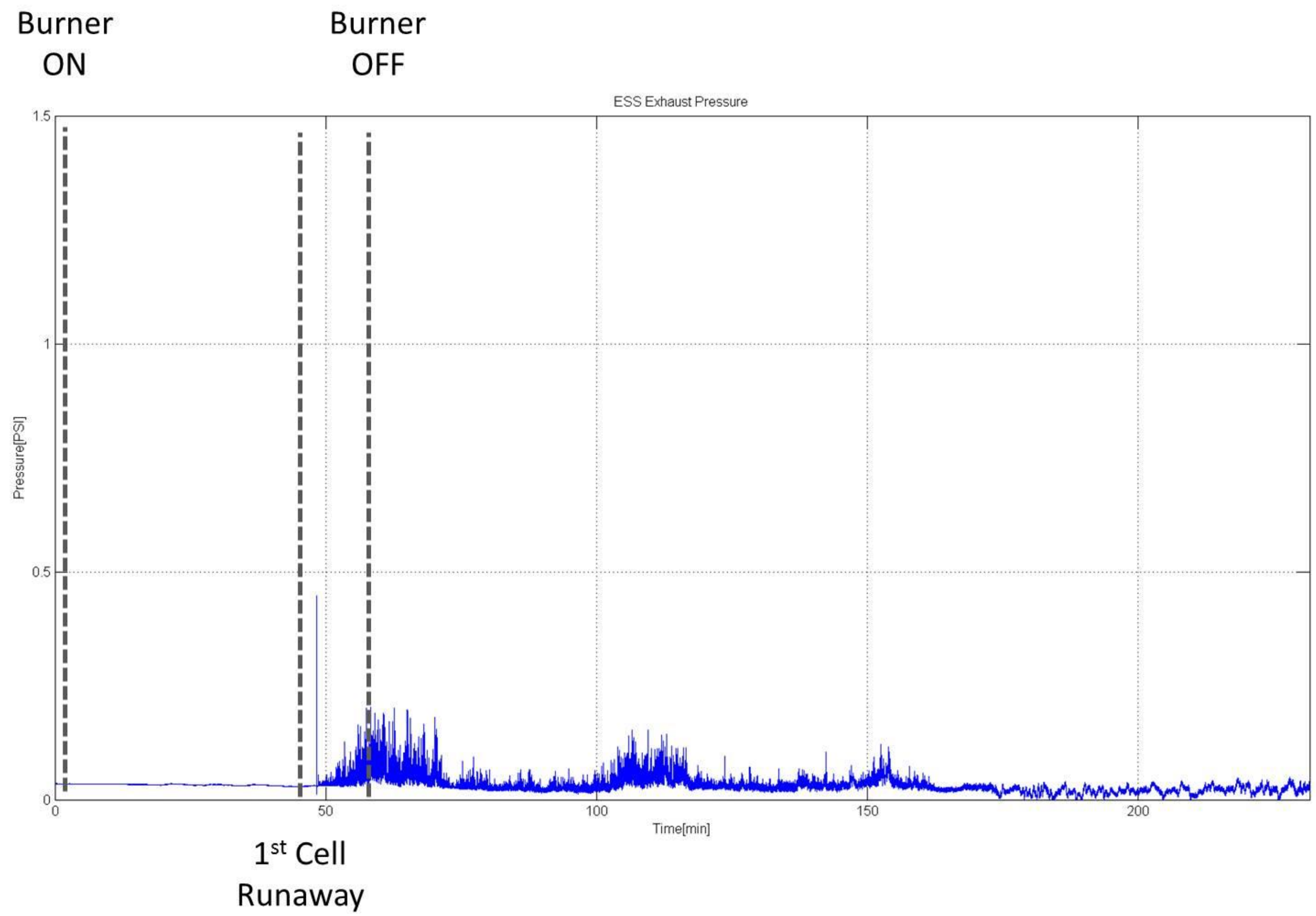

Figure 42 Exhaust manifold pressure

Appendix C: External Ignition Test: Gas Sampling Plot

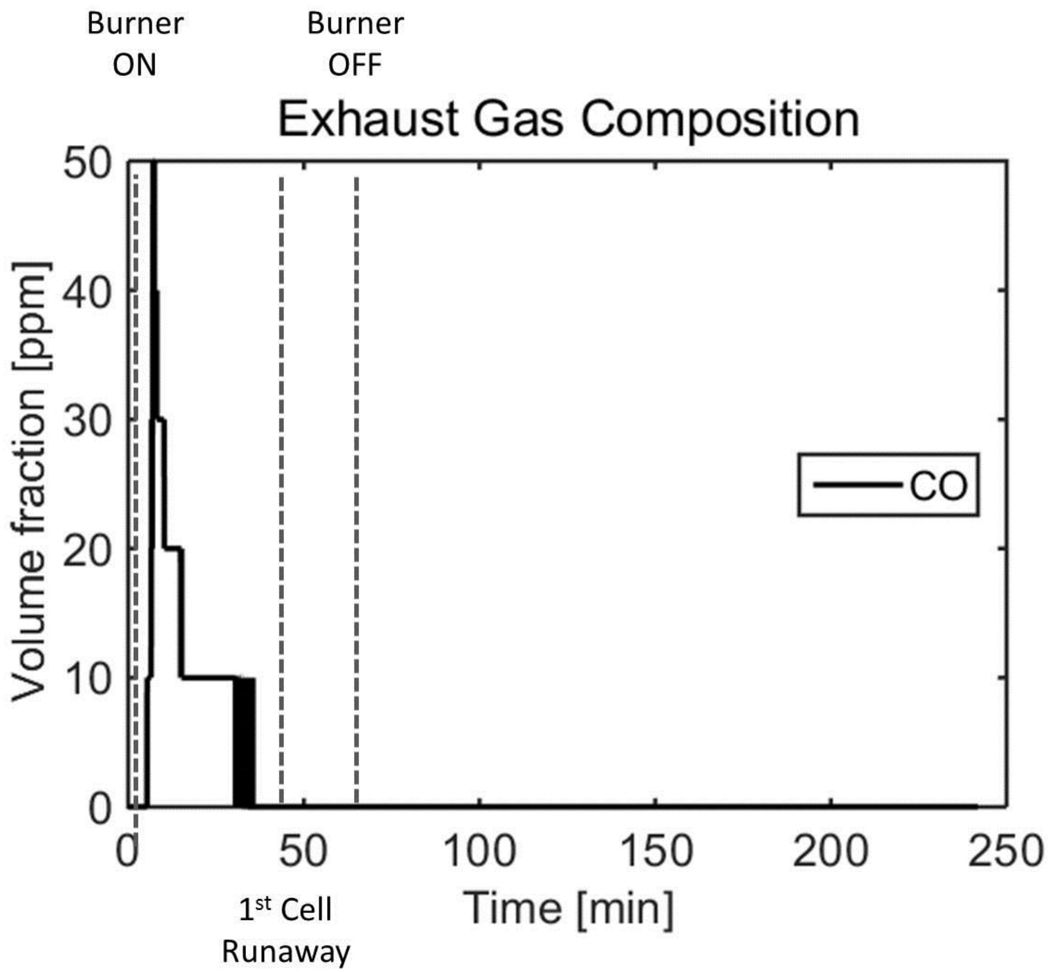

Figure 43 CO detected at the exhaust vent

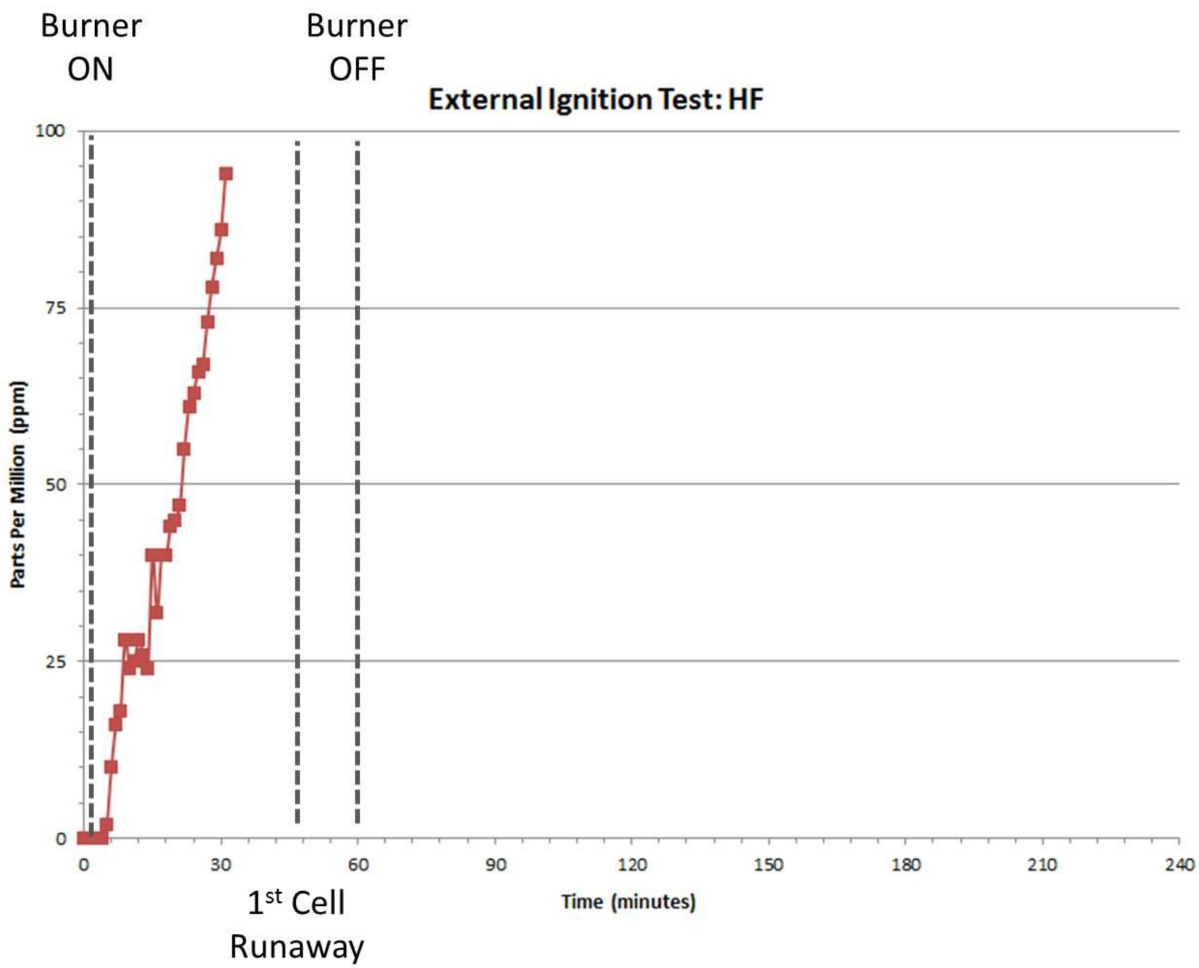

Figure 44 HF detected at the exhaust vent (detector maximum range was 100 ppm; all measurements after minute 30 were "over range," indicating the HF values were greater than 100 ppm for the remainder of the test

Appendix D: Internal Ignition Test: Temperature Plots

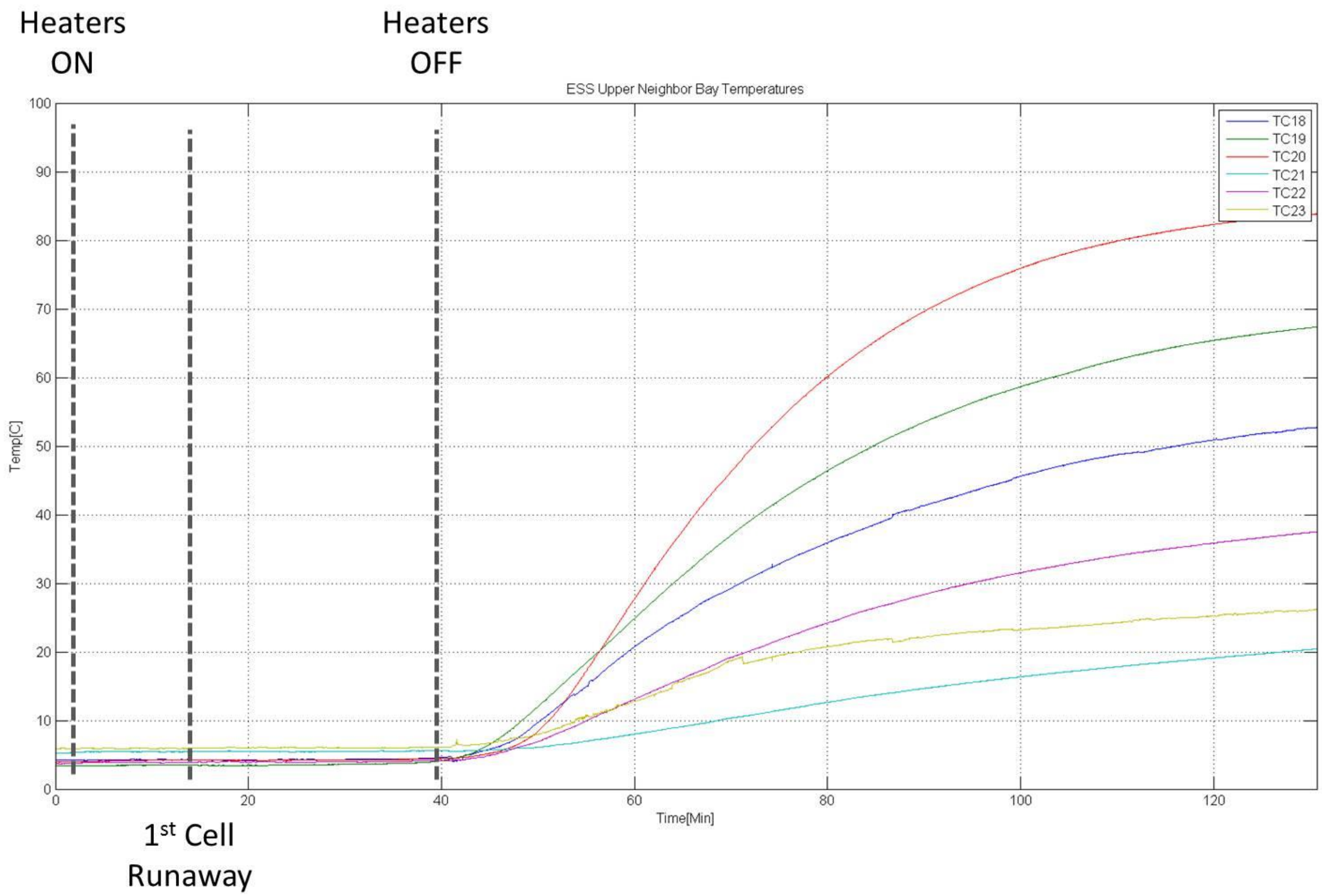

Figure 45 Pod 7 temperatures

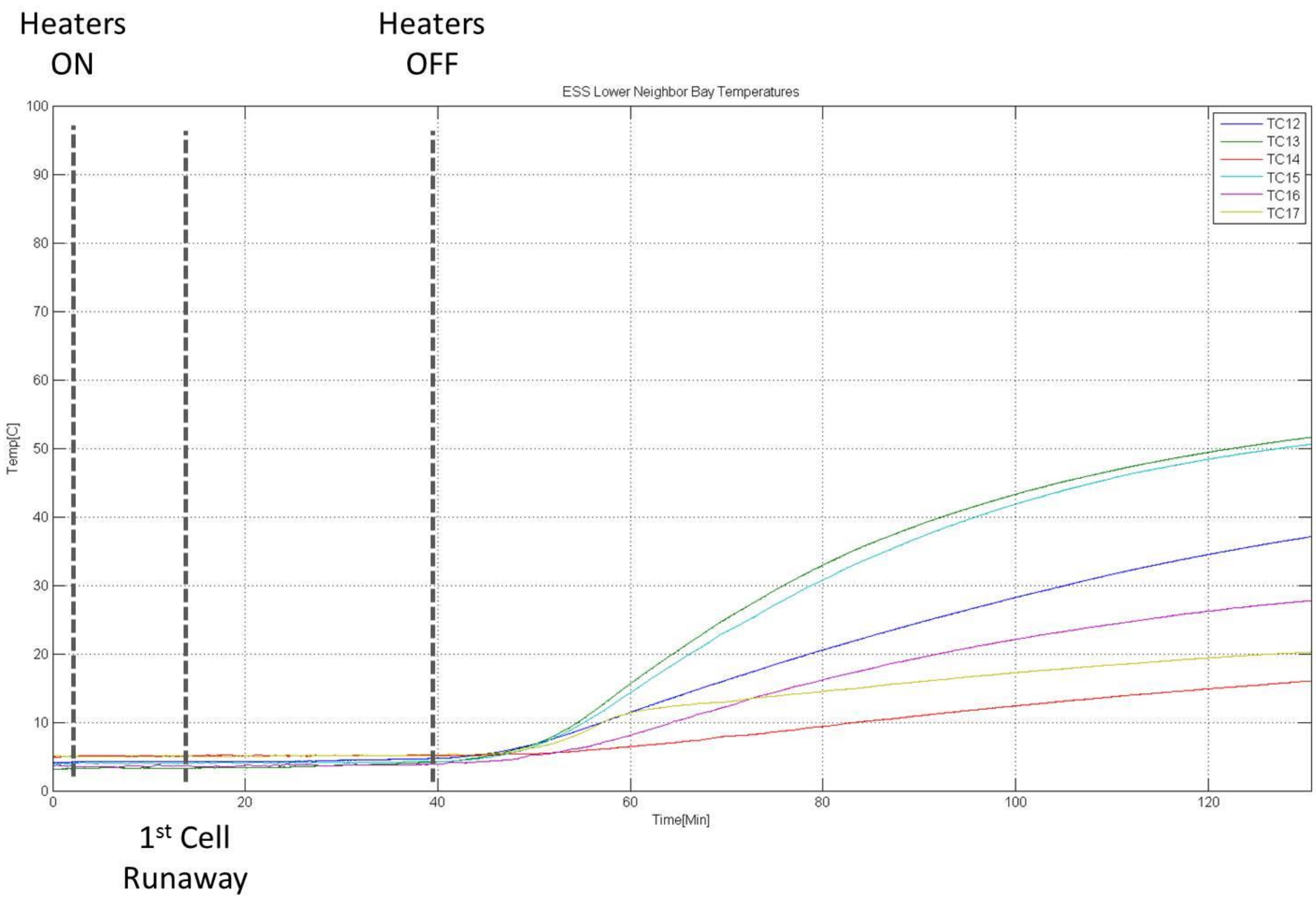

Figure 46 Pod 5 temperatures

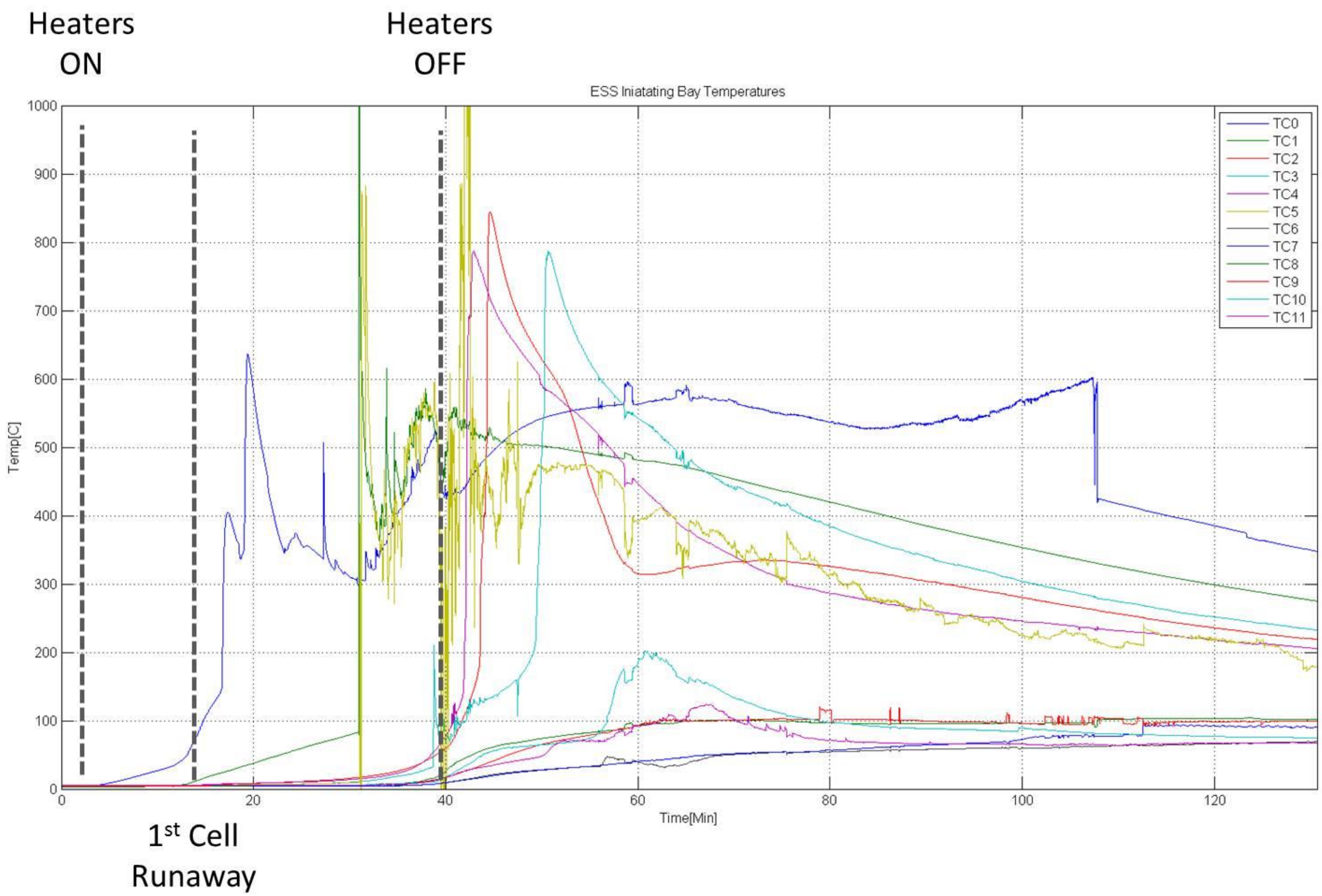

Figure 47 Pod 6 (initiator pod) temperatures (noise observed in the data is consistent with electrical interference that occurs during voltage leakage from the damaged batteries after thermal runaway)

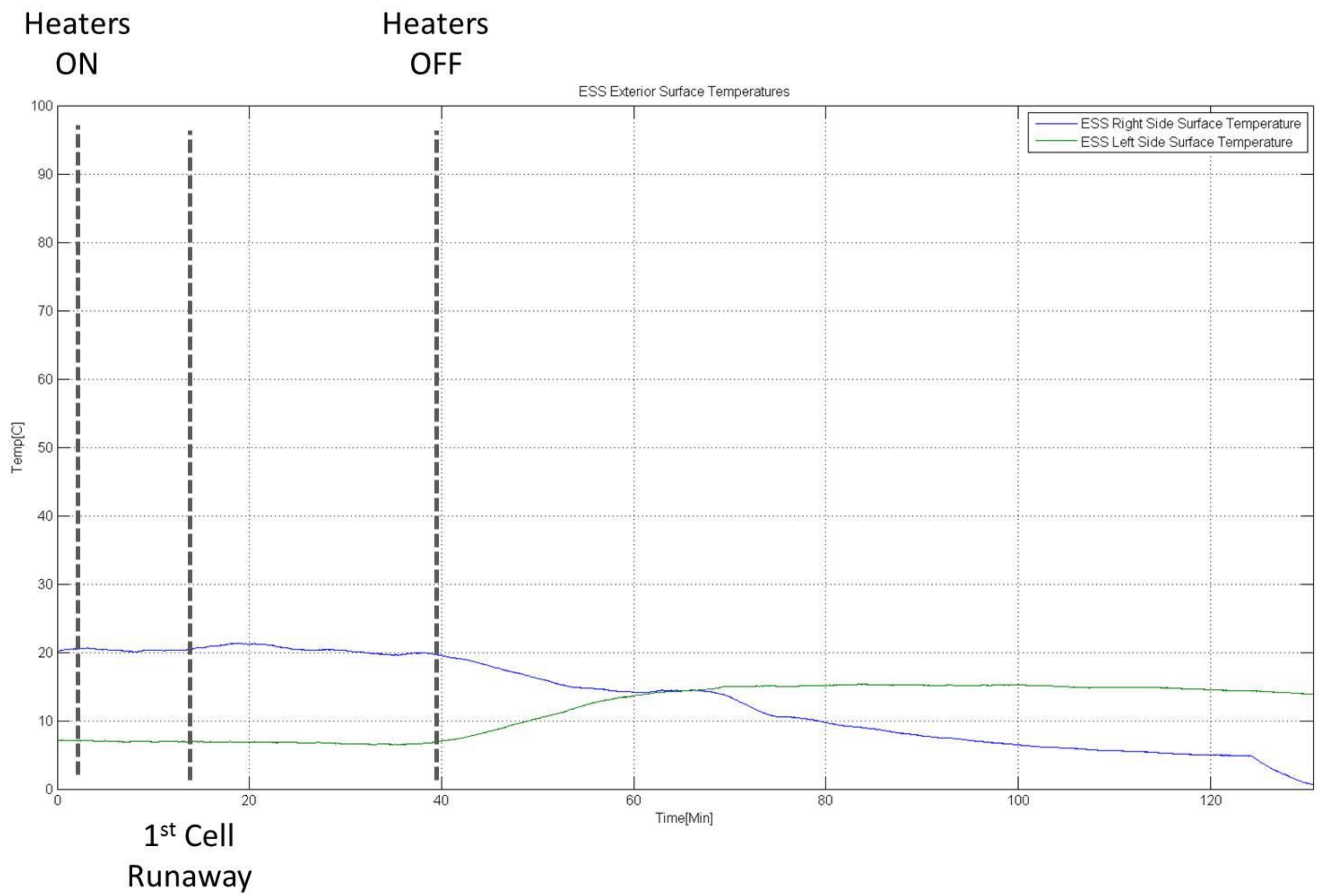

Figure 48 Exterior Powerpack surface temperatures

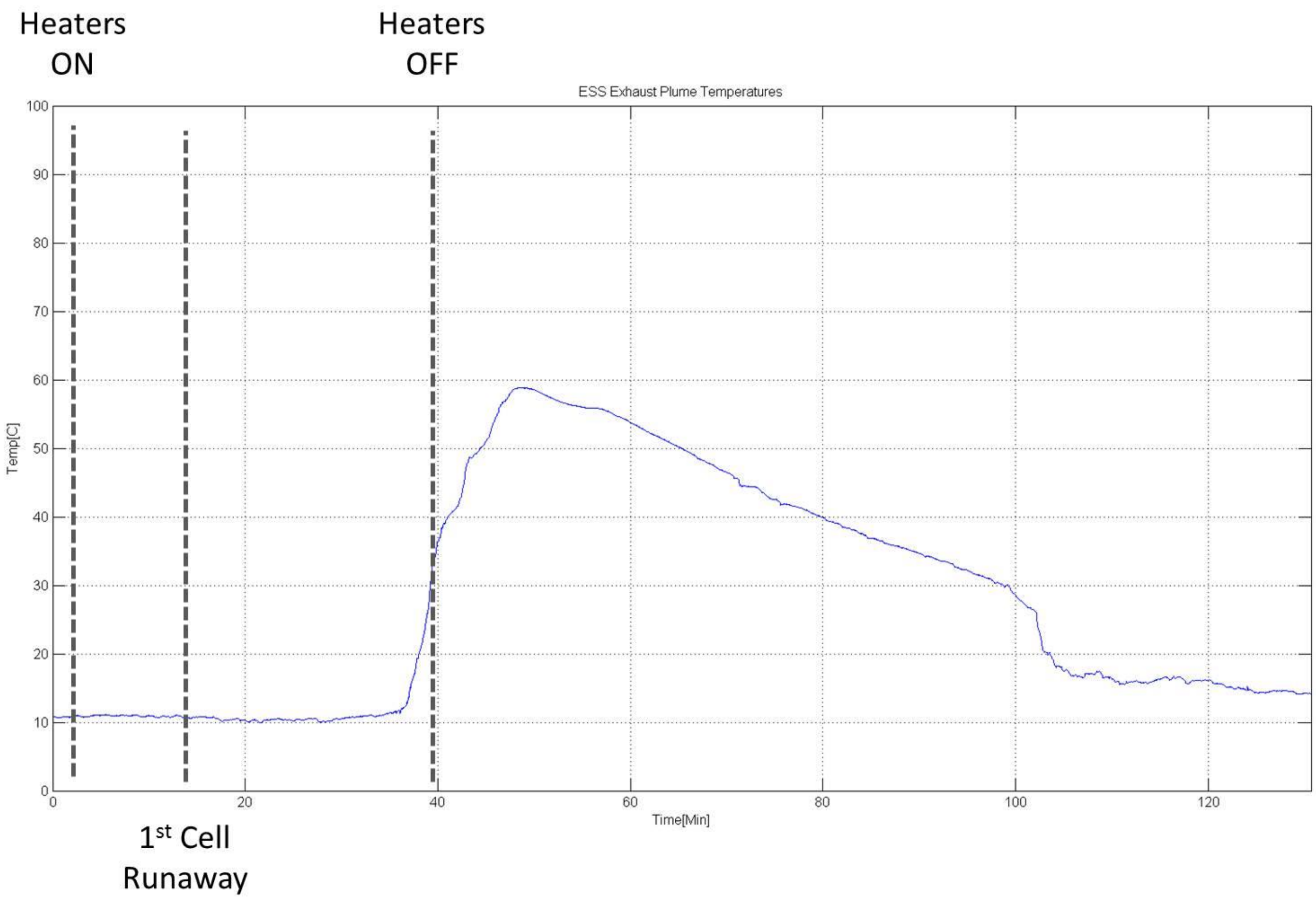

Figure 49 Exhaust vent temperature

Appendix E: Internal Ignition Test: Pressure Plots

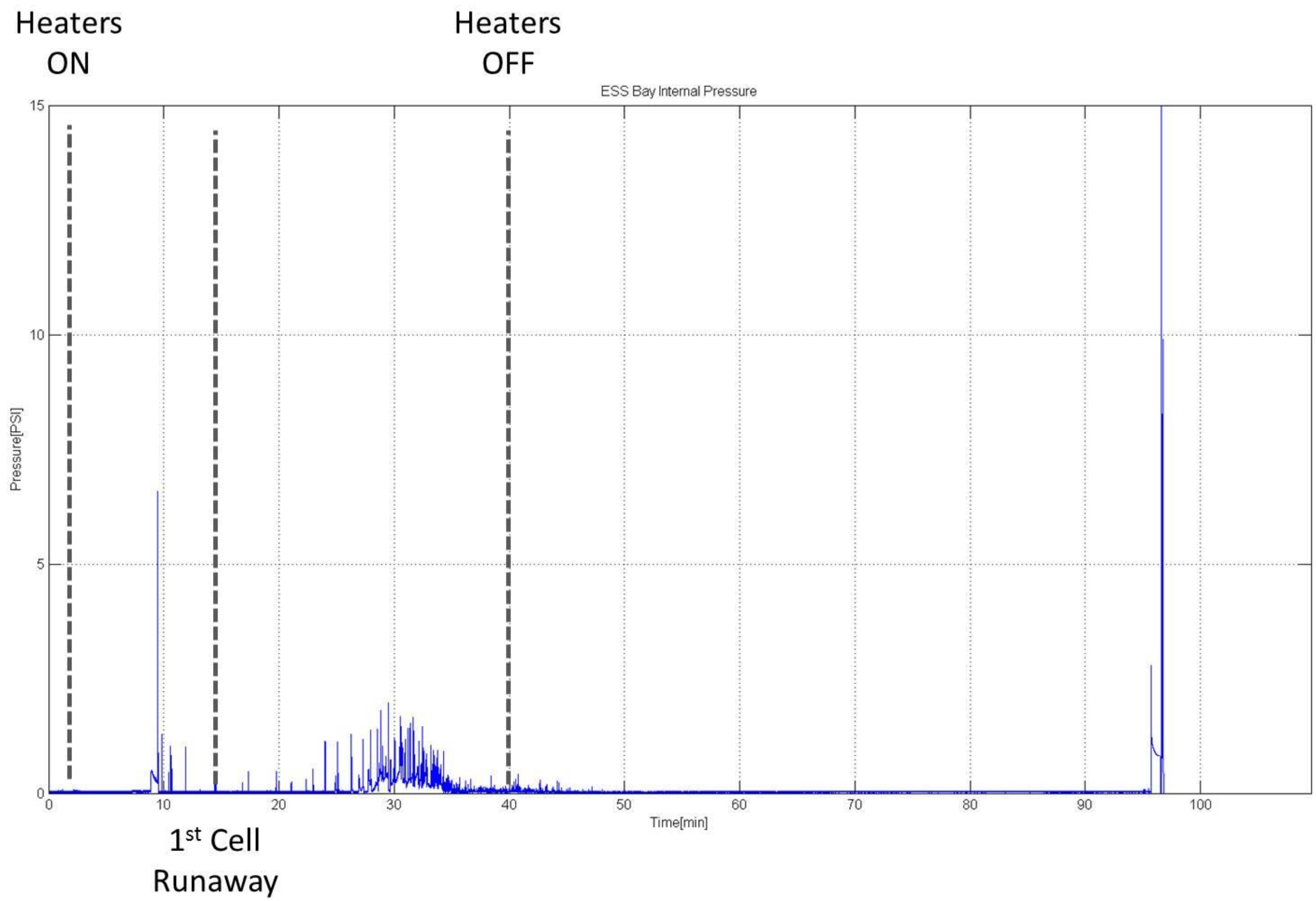

Figure 50 Pod 6 (initiator pod) pressure

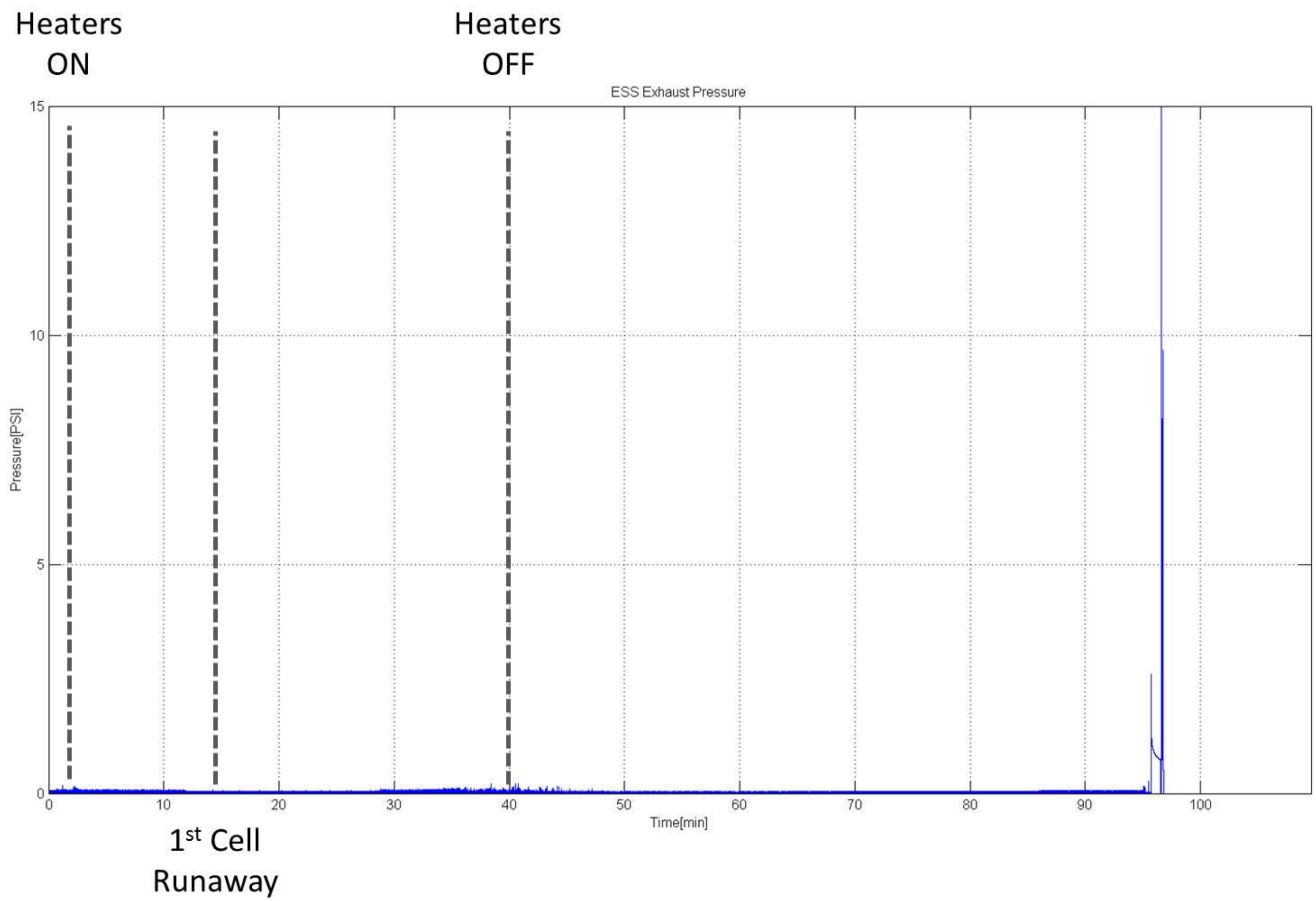

Figure 51 Powerpack exhaust manifold pressure

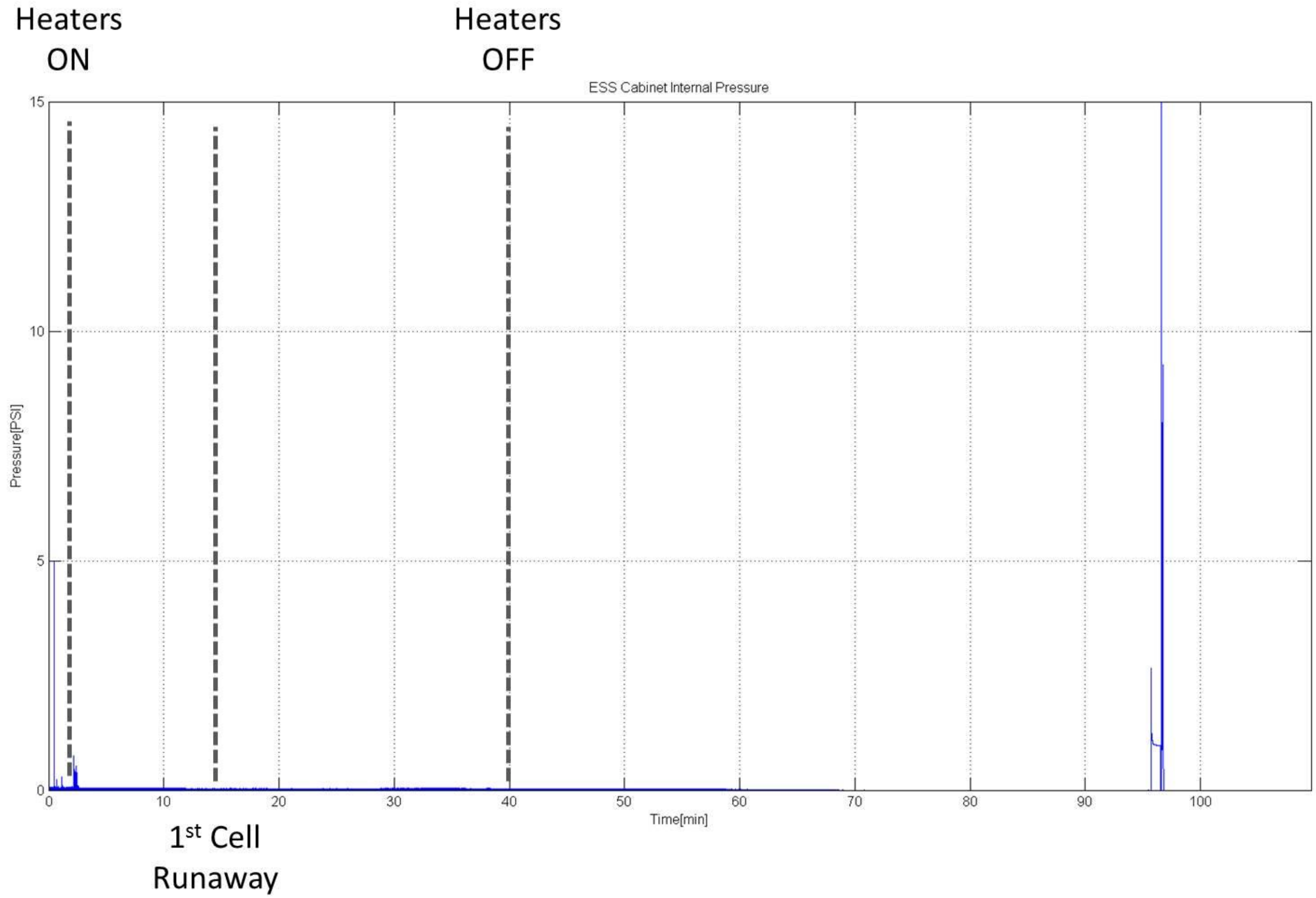

Figure 52 Powerpack cabinet pressure

Appendix F: Internal Ignition Test: Gas Sampling Plot

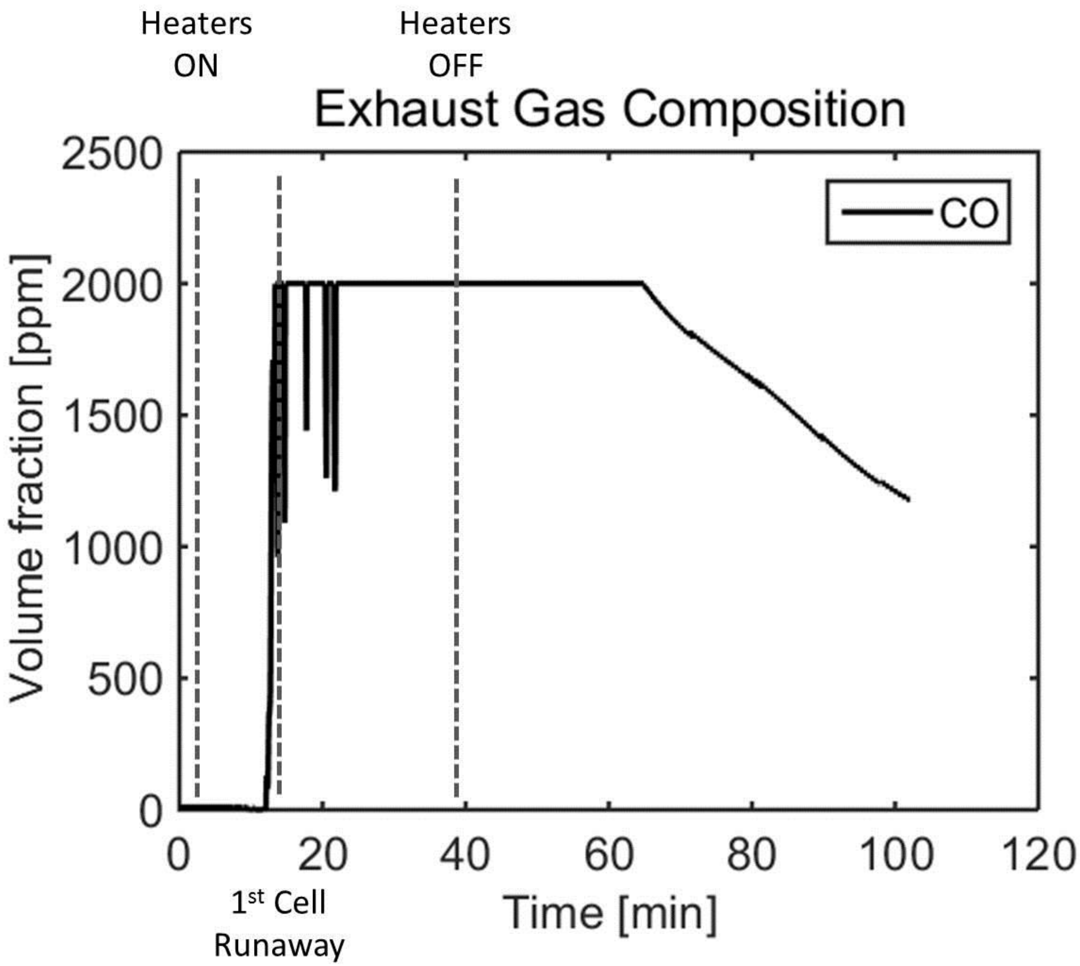

Figure 53 CO detected at exhaust vent

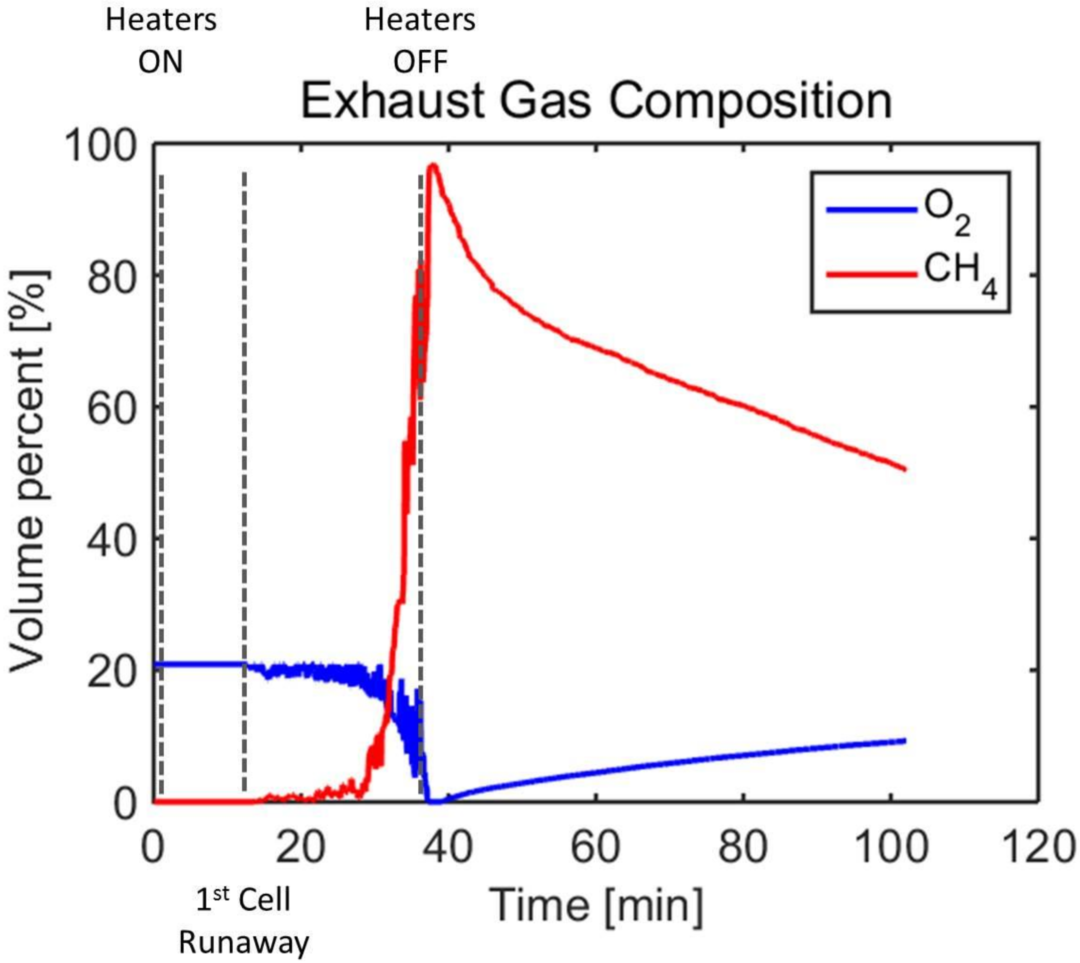

Figure 54 CH_4 detected at exhaust vent

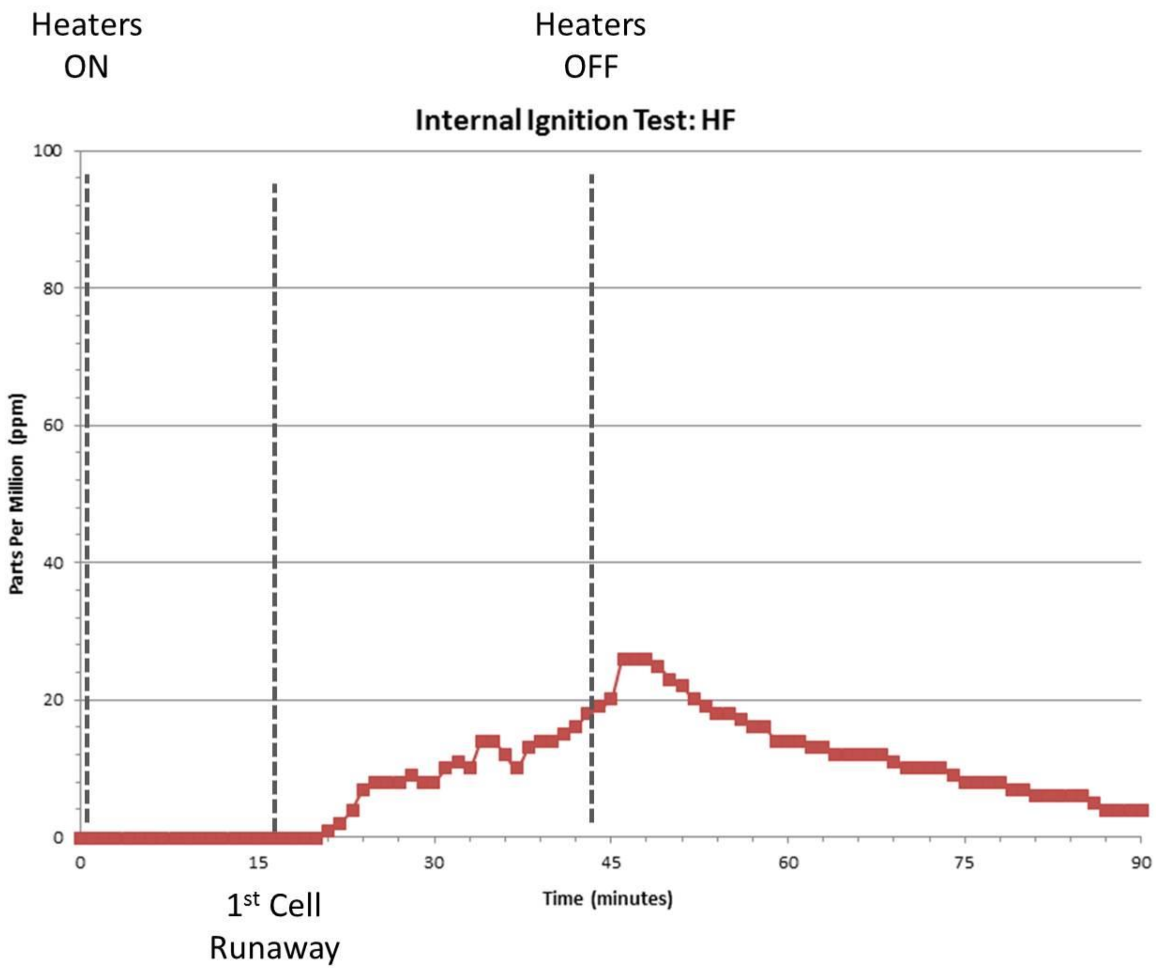

Figure 55 HF detected at the exhaust vent

SECTION 4.5

HAZARDS AND HAZARDOUS MATERIALS

This section describes federal, state and local regulations applicable to hazards and hazardous materials. It also describes the environmental setting with regard to potential hazards associated with implementation of the proposed Battery Energy Storage System. It focuses on hazardous materials, fire safety and mechanisms to prevent accidental release/explosion. Measures are identified to reduce or avoid adverse impacts anticipated from construction, operation, and decommissioning of the proposed Project. A discussion of cumulative impacts related to hazards and hazardous materials is also included in this section.

This analysis does not address the potential exposure of workers to hazardous materials used at the proposed Project site. Employers must inform employees of hazards associated with their work and provide those employees with special protective equipment and training to reduce the potential for health impacts from the handling of hazardous materials.

Seismic hazards, flood hazards and exposure to noise are discussed in Section 4.4, Geology and Soils and Section 4.6, Noise.

4.5.1 REGULATORY FRAMEWORK

A. FEDERAL

Resource Conservation and Recovery Act of 1976 (42 USC 6901 et seq.)

The Resource Conservation and Recovery Act (RCRA) grants authority to the Environmental Protection Agency (EPA) to control hazardous waste from start to finish. This covers the production, transportation, treatment, storage, and disposal of hazardous waste. The RCRA also sets forth a framework for the management of non-hazardous solid waste. The 1986 amendments to the RCRA enabled the EPA to address environmental problems that could result from underground tanks storing petroleum and other hazardous substances. Small quantities of hazardous materials will be used and stored on-site during operations and maintenance of the Project.

Federal Water Pollution Control Act (Clean Water Act)

The Federal Water Pollution Control Act, better known as the Clean Water Act (CWA), is a comprehensive statute focused on restoring and maintaining the chemical, physical and biological integrity of the nation's waters. Originally enacted in 1948, the Act was amended numerous times until it was reorganized and expanded in 1972. It continues to be amended almost on an annual basis.

Primary authority for the implementation and enforcement of the CWA rests with the EPA. The CWA authorizes water quality programs, requires federal effluent limitations and state water quality standards, requires permits for the discharge of pollutants into navigable waters, provides enforcement mechanisms, and authorizes funding for wastewater treatment works construction grants and state revolving loan programs, as well as funding to states and tribes for their water quality programs. Provisions have also been added to address water quality problems in specific regions and specific waterways.

During construction of the proposed Project, a National Pollution Discharge Elimination Permit (NPDES) permit will not be required for Phase 1 because less than one acre would be disturbed. However, a NPDES Small Construction Waiver will need to be submitted for Phase 2 of the Project because more than 1 acre, but less than 5 acres would be disturbed. The Battery Energy Storage System does not propose any features that would degrade water quality once operational.

Occupational Safety and Health Act (OSHA)

Congress passed the Occupational Safety and Health Act (OSHA) to assure safe and healthful working conditions for working men and women. OSHA authorized enforcement of the standards developed under the Act and by assisted States in its efforts to assure safe and healthful working conditions. OSHA also provides for research, information, education, and training in the field of occupational safety and health. The project would be subject to OSHA requirements during construction, operations and maintenance and decommissioning.

Title 47, CFR, section 15.2524, Federal Communications Commission (FCC)

Title 47, CFR, Section 15.2524, Federal Communications Commission (FCC) prohibits operation of devices that can interfere with radio-frequency communication. All of the batteries used at the facility will be UL and should not have any effect on radio frequency. All of the equipment associated with the charge/discharge of energy from the batteries is specified at 60Hz which is on the lower range of radio frequencies (Southern Power Company 2016).

B. STATE

Title 22 of the California Code of Regulations

Hazardous Materials Defined

A material is considered hazardous if it appears on a list of hazardous materials prepared by a federal, state, or local agency, or if it has characteristics defined as hazardous by such an agency. According to Title 22, Section 66260.10, of the California Code of Regulations (CCR), a hazardous material is defined as:

> *…A substance or combination of substances which because of its quantity, concentration, or physical, chemical or infectious characteristics, may either (1) cause, or significantly contribute to an increase in mortality or an increase in serious irreversible, or incapacitating reversible, illness; or, (2) pose a substantial present or potential hazard to human health or environment when improperly treated, stored, transported or disposed of or otherwise managed.*

Chemical and physical properties that cause a substance to be considered hazardous include the properties of toxicity, ignitability, corrosivity, and reactivity (Title 22, Sections 66261.20 through 66261.24). Factors that influence the health effects of exposure to hazardous materials include dosage, frequency, the exposure pathway, and individual susceptibility. The proposed Battery Energy Storage System would require use of small amounts of hazardous materials (such as diesel fuel, oil and grease for heavy equipment) during construction, maintenance and decommissioning. During operation, the Project would place lithium ion batteries next to the Campo Verde Substation. The batteries would be house in a container and structure with a fire safety system.

California Environmental Protection Agency

The California Environmental Protection Agency (Cal EPA) and the State Water Resources Control Board (SWRCB) establish rules governing the use of hazardous materials and the management of hazardous waste. Applicable state and local laws include the following:

- Public Safety/Fire Regulations/Building Codes
- Hazardous Waste Control Law
- Hazardous Substances Information and Training Act
- Air Toxics Hot Spots and Emissions Inventory Law
- Underground Storage of Hazardous Substances Act
- Porter-Cologne Water Quality Control Act

The use of lithium ion batteries proposed as part of the Project would be subject to state and local laws.

Department of Toxic Substances Control

The Department of Toxic Substances Control (DTSC) has primary regulatory responsibility for the management of hazardous materials and the generation, transport, and disposal of hazardous waste under the authority of the Hazardous Waste Control Law (HWCL). Enforcement is delegated to local jurisdictions that enter into agreements with DTSC.

California's Secretary of Environmental Protection established a unified hazardous waste and hazardous materials management regulatory program as required by Health and Safety Code Chapter 6.11. The unified program consolidates, coordinates, and makes consistent portions of the following six existing programs:

- Hazardous Waste Generations and Hazardous Waste On-site Treatment
- Underground Storage Tanks
- Hazardous Material Release Response Plans and Inventories
- California Accidental Release Prevention Program
- Aboveground Storage Tanks (spill control and countermeasure plan only)
- Uniform Fire Code Hazardous Material Management Plans and Inventories

The statute requires all counties to apply to the Cal EPA Secretary for the certification of a local unified program agency. Qualified cities are also permitted to apply for certification. The local Certified Unified Program Agency (CUPA) is required to consolidate, coordinate, and make consistent the administrative requirements, permits, fee structures, and inspection and enforcement activities for these six program elements within the county. Most CUPAs have been established as a function of a local environmental health or fire department.

The Office of the State Fire Marshal participates in all levels of the CUPA program including regulatory oversight, CUPA certifications, evaluations of the approved CUPAs, training, and education. The DTSC serves as the CUPA in Imperial County.

Small quantities of hazardous materials will be transported to and from the project site and used and stored on-site for miscellaneous, general operations and maintenance activities. In addition, lithium ion batteries (housed in a container and structure equipped with a fire safety system) will also be placed on the Project site.

Title 8, California Code of Regulations (CCR) section 2700 et seq. "High Voltage Safety Orders"

Title 8 of the California Code of Regulations specifies requirements and minimum standards for safety when installing, operating, working around, and maintaining electrical installations and equipment. The proposed Project would be subject to Title 8.

National Electrical Safety Code (NESC)

The National Electrical Safety Code specifies grounding procedures to limit nuisance shocks and specifies minimum conductor ground clearances. The proposed Project would be subject to this code and would be designed with a grounding system providing an adequate path-to-ground to permit the dissipation of current created by lightning and ground faults.

14 California Code of Regulations (CCR), Sections 1250 – 1258, "Fire Prevention Standards for Electric Utilities"

14 CCR provides specific exemptions from electric pole and tower firebreak. 14 CCR also provides conductor clearance standards and specifies when and where standards apply. These standards address hazards that could be caused by sparks from conductors of overhead lines, or that could result from direct contact between the line and combustible objects. The proposed Project would be subject to these standards.

2013 California Fire Code

The 2013 California Fire Code (CFC) is an enforceable set of regulations for the safeguarding of life and property from fire and explosion hazards arising from the storage, handling and use of hazardous substances, materials and devices, and from conditions hazardous to life or property in the occupancy of buildings and premises.

The purpose of this code is to establish the minimum requirements consistent with nationally recognized good practices to safeguard the public health, safety and general welfare from the hazards of fire, explosion or dangerous conditions in new and existing buildings, structures and premises, and to provide safety and assistance to fire fighters and emergency responders during emergency operations (CFC 2013).

The Imperial County Fire Department (ICFD) adheres to and enforces the regulations contained in the 2013 CFC.

C. LOCAL

County of Imperial General Plan

Both natural and man-made hazards are addressed in the County of Imperial General Plan. The Seismic and Public Safety Element also contains a set of goals and objectives for land use planning and safety, emergency preparedness, and the control of hazardous materials. The goals and objectives, together with the implementation programs and policies provide direction for development.

Table 4.5-1 analyzes the consistency of the proposed Battery Energy Storage System with the applicable goal and objectives relating to public safety in the County of Imperial General Plan. While this SEIR analyzes the Project's consistency with the General Plan pursuant to CEQA Guidelines Section 151250, the Imperial County Board of Supervisors ultimately determines consistency with the General Plan.

TABLE 4.5-1
IMPERIAL COUNTY GENERAL PLAN CONSISTENCY ANALYSIS

General Plan Policies	Consistent with General Plan?	Analysis
Public Safety Policies		
Control Hazardous Materials		
Goal 3: Protect the public from exposure to hazardous materials and wastes.	Yes	The County has adopted an Emergency Operations Plan and a Fire Prevention and Explosives Ordinance to protect the public from exposure to hazardous materials wastes. The proposed Project is located in

TABLE 4.5-1
IMPERIAL COUNTY GENERAL PLAN CONSISTENCY ANALYSIS

General Plan Policies	Consistent with General Plan?	Analysis
		a rural and unpopulated portion of the County. The Battery Energy Storage System does not involve exposure of the public to hazardous materials and wastes. Prior to using or storing hazardous materials on the Project site, the Applicant will update the existing Hazardous Material Business Plan (HMBP) prepared for the Campo Verde Solar Project to include the Battery Energy Storage System. Thus, the proposed Project is consistent with this goal.
Objective 3.1 Discourage the transporting of hazardous materials/waste near or through residential areas and critical facilities.	Yes	The Battery Energy Storage System site is not near any residential uses or critical facilities such as a hospital or fire station. Large quantities of hazardous materials are not required as part of construction, operation, or decommissioning of the proposed Project. While lithium ion batteries can be flammable, they would be enclosed, equipped with a fire safety system and would be required to meet all applicable California Fire Codes. Therefore, the proposed Project is consistent with this objective.
Objective 3.2 Minimize the possibility of hazardous materials/waste spills.	Yes	As noted under the analysis for Goal 3, prior to using or storing hazardous materials on the Project site, the Applicant will update the existing HMBP prepared for the Campo Verde Solar Project to include the proposed Battery Energy Storage System. In addition, special precautions would be implemented to avoid accidental spills while refueling equipment during construction. Therefore, the proposed Project is consistent with this objective.
Objective 3.3 Discourage incompatible development adjacent to sites and facilities for the production, storage, disposal, and transport of hazardous	Yes	The Project site is within the boundaries of the Campo Verde Solar Project. The proposed Battery Energy Storage System is compatible with surrounding uses and the Project site is not adjacent to any

TABLE 4.5-1
IMPERIAL COUNTY GENERAL PLAN CONSISTENCY ANALYSIS

General Plan Policies	Consistent with General Plan?	Analysis
materials/waste as identified in the County General Plan and other regulations.		hazardous materials/waste facilities. Therefore, the proposed Project is consistent with this objective.

Imperial County Office of Emergency Services – Emergency Operations Plan

The Imperial County Fire Department (ICFD) is the local Office of Emergency Services (OES) in Imperial County. The County Fire Chief is the OES Coordinator. An Assistant OES Coordinator maintains the OES program for the County of Imperial. ICFD acts as the lead agency for the Imperial County Operational Area (OA) and provides leadership in all phases of developing the emergency management organization, including public education, training, EOC operations, interagency coordination, and plan development (Imperial County OES 2007).

The Imperial County Emergency Operations Plan (EOP) provides a comprehensive, single source of guidance and procedures for the County to prepare for and respond to significant or catastrophic natural, environmental, or conflict-related risks that produce situations requiring coordinated response. It further provides guidance regarding management concepts relating to response and abatement of various emergency situations, identifies organizational structures and relationships, and describes responsibilities and functions necessary to protect life and property. The EOP is consistent with the requirements of the Standardized Emergency Management System (SEMS) as defined in Government Code Section 8607(a) and the U.S. Department of Homeland Security National Incident Management System (NIMS) for managing response to multi-agency and multi-jurisdictional emergencies. SEMS/NIMS incorporates the use of the Incident Command System (ICS), mutual aid, the operational area concept, and multi/interagency coordination (Imperial County OES, 2007). The Battery Energy Storage System site is in Zone 1-B of Fire/Emergency Management/Staging and Shelter Zones in the EOP (Imperial County OES 2007, p. 73).

County of Imperial Fire Prevention and Explosives Ordinance

The County of Imperial Fire Prevention and Explosives Ordinance, Section 53101-53300, contains provisions for the purpose of prescribing regulations governing conditions hazardous to life and property from fire or explosion. Such measures in this Ordinance include the following:

- Storage of flammable materials
- Storage of radioactive materials
- Permit required for sale and use of fireworks
- Abatement of weeds and other vegetation

Weed and vegetation control is currently enforced as part of operations and maintenance of Campo Verde Solar Project. The Integrated Pest Management Plan for Private Lands Campo Verde Solar Project (Heritage 2012c) will be revised to include the proposed Battery Energy Storage System site. Provisions pertaining to the storage of flammable materials (i.e. lithium ion batteries) would apply to the proposed Battery Energy Storage System. The existing Campo Verde Solar Project Hazardous Materials Business Plan will be updated to incorporate the hazardous materials associated with the lithium ion battery storage systems including the location, quantity, composition and storage conditions.

4.5.2 ENVIRONMENTAL SETTING

The Battery Energy Storage System is proposed within the existing boundaries Campo Verde Solar Project to the west of the Campo Verde Substation. The Substation is located west of Liebert Road, south of Wixom Road and north of Mandrapa Road (see Figure 2.0-2 in Chapter 2.0). The proposed Battery Energy Storage System site is immediately to the west of the Substation (see Figure 2.0-3 in Chapter 2.0). There is one access to the Substation off of Liebert Road which would be extended approximately 1,000 feet from the terminus of the existing paved access road.

Phase I Environmental Site Assessment

A Phase I Environmental Site Assessment was prepared for the Campo Verde Solar Project site (URS 2012). The Phase I ESA encompassed the Battery Energy Storage System site. The Phase I ESA was prepared to determine if any recognized or potential environmental conditions are present within the boundaries of the Campo Verde Solar Project. The American Society for Testing and Materials (ASTM) defines "recognized environmental conditions" as "any hazardous substance or petroleum product under conditions that indicate an existing, past, or material threat of release into the structures, ground, groundwater, or surface water at the subject site."

The Phase I ESA included results of a site reconnaissance to identify conditions of the Campo Verde Solar Project site and adjoining properties prior to development of the project. The Phase I ESA included, a review of various readily available federal, state, and local government agency records, and review of available historical site and site vicinity information. A review of the Phase I ESA revealed that Assessor's Parcel Number (APN) 051-350-014 (now 051-350-018) had a shade/shelter structure in the central portion of the property as well as a bee box shade structure on the southern side of the parcel (URS 2012, p. 2-2 and p. A-9). These structures did not contain any hazardous materials and were removed when the Campo Verde Solar Project was constructed.

Emergency Plans

The County of Imperial has adopted the "Imperial County Operational Area - Emergency Operations Plan," which addresses the County's planned response to extraordinary emergency situations associated with natural disasters, technological incidents, and nuclear defense operations. The plan identifies certain open space areas and public buildings to serve as emergency shelters when residents must be relocated. No portion of the Campo Verde Solar Project, including the Battery Energy Storage System site, is designated as an emergency shelter area on the Fire/Emergency Management/Staging and Shelter Zone Map (Imperial County OES 2007).

Fire Hazard

The potential for a major fire in the unincorporated areas of the County is generally low. According to the Imperial County Natural Hazard Disclosure (Fire) Map prepared by the California Department of Forestry and Fire Protection (CDF 2000), the Campo Verde Solar Project, including the Battery Energy Storage System site, is not located in an area characterized as either: (1) a wildland area that may contain substantial forest fire risk and hazard; or (2) very high fire hazard severity zone. The closest wildland area prone to forest fire is located is approximately 20 miles west of the Project site.

Valley Fever

Valley Fever is an illness caused by a fungus (*Coccidioides immitis* and C. *posadasii*) that grows in soils under certain conditions. Favorable conditions for the Valley Fever fungus include low rainfall, high summer temperatures, and moderate winter temperatures. Soils within the Imperial Valley, including the Project site, fit the profile to harbor Valley Fever spores. When soils are disturbed by the wind or other activities such as construction and farming, Valley Fever fungal spores become airborne. The spores present a potential health hazard when inhaled. Individuals in occupations such as construction, agriculture, and archaeology have a higher risk of exposure due to working in areas of disturbed soils which may have the Valley Fever fungus. Infection risk is highest in California during a six-month period from June to November. Animals are also susceptible to the disease. In extreme cases, the disease can be fatal, though the majority of Valley Fever cases are very mild with over 60 percent or more of infected people having no symptoms or flu-like symptoms (BLM 2010a). Imperial County has a relatively low Valley Fever incidence rate of 0.1 to 5 cases for every 100,000 people (CDPH 2009).

4.5.3 IMPACTS AND MITIGATION MEASURES

A. STANDARDS OF SIGNIFICANCE

The impact analysis provided below is based on the following State CEQA Guidelines, as listed in Appendix G. The Project would result in a significant impact to hazards and hazardous materials if it would result in any of the following:

a) Create a significant hazard to the public or the environment through the routine transport, use, or disposal of hazardous materials?

b) Create a significant hazard to the public or the environment through reasonably foreseeable upset and accident conditions involving the release of hazardous materials into the environment?

c) Emit hazardous emissions or handle hazardous or acutely hazardous materials, substances, or waste within one-quarter mile of an existing or proposed school?

d) Be located on a site which is included on a list of hazardous materials sites compiled pursuant to Government Code Section 65962.5 and, as a result, would it create a significant hazard to the public or the environment?

e) For a project located within an airport land use plan or, where such a plan has not been adopted, within two miles of a public airport or public use airport, would the project result in a safety hazard for people residing or working in the project area?

f) For a project within the vicinity of a private airstrip, would the project result in a safety hazard for people residing or working in the project area?

g) Impair implementation of or physically interfere with an adopted emergency response plan or emergency evacuation plan?

h) Expose people or structures to a significant risk of loss, injury or death involving wildland fires, including where wildlands are adjacent to urbanized areas or where residences are intermixed with wildlands?

B. Issues Scoped Out

Several criteria were eliminated from further evaluation as part of the CEQA Appendix G Environmental Checklist Form. Criterion "c" because the Project site is not located within one-quarter mile of an existing school. Furthermore, the Project would not create any hazardous emissions. Therefore, this issue is not discussed further.

Criterion "d" was eliminated because the Battery Energy Storage System site is not listed as a hazardous materials site pursuant to Government Code, Section 65962.5. Therefore, this issue is not discussed further.

Criteria "e" and "f" were eliminated because the Battery Energy Storage System site is not located within two miles of a public airport or a private airstrip. Therefore, this issue is not discussed further.

Criterion "d" was eliminated because the proposed Project would not interfere with an adopted emergency response plan or evacuation plan. As identified in the Seismic and Public Safety Element of the County of Imperial General Plan, the "Imperial County Emergency Plan" addressed Imperial County's planned response to extraordinary emergency situations associated with natural disasters, technological incidents, and nuclear defense operations. The proposed circulation plan for the Battery Energy Storage System site will be required to provide emergency access points and safe vehicular travel. In addition, local and state building codes would be followed to minimize flood, seismic, and fire hazard. Thus, the proposed Project would not impair the implementation or physically interfere with any adopted emergency response plans or emergency evacuation plans. No impact is identified for this issue and it is not discussed in the SEIR.

Criterion "h" was eliminated because the Battery Energy Storage System site is not characterized as an area of urban/wildland interface. According to the Imperial County Natural Hazard Disclosure (Fire) Map prepared by the California Department of Forestry and Fire Protection (2000) the Project site does not fall into an area characterized as either: (1) a wildland area that may contain substantial forest fire risk and hazard; or (2) very high fire hazard severity zone. Thus, the Project site would not expose people or structures to significant risk of loss injury or death involving wildland fire. No impact is identified for this issue area and it is not discussed further.

C. Issues of Concern with No Applicable Criteria

Several hazards of potential concern to the public with no corresponding criteria are briefly discussed below. These hazards are acknowledged and discussed to the extent that they would result from the proposed Project.

<u>Hazardous Shocks</u>

The area located in the vicinity of the battery container and building and components will be designed and constructed for lightning protection in accordance with NFPA Standard 780, UL 96 and 96A, and local applicable codes and standards (Southern Power Company 2016).

Grounding will be designed as required by IEEE, NEC, NESC, and local code requirements. The ground grid or ground loop will be provided under/around major electrical equipment (step-up transformers, medium voltage switchgear, inverters, etc.) The grounding system will consist of bare copper conductor and copper-clad steel or stainless steel ground rods. Ground rods will be copper clad, cold drawn carbon steel, manufactured in accordance with UL 467. Individual ground rods will be at least 5/8-inch diameter and 10 feet long. Ground lugs will be single-hole or two-hole, heavy-duty, copper bars conforming to the requirements of IEEE 837 and UL 467.

Ground bus bar shall be soft drawn, uncoated copper conforming to the requirements of ASTM B-187. The Module direct current (DC) system grounding electrode(s) will be common with, or bonded to, the alternating current (AC) grounding electrode as indicated in NEC Article 690.47. The design shall also conform to IEEE Standard 665 (Southern Power Company 2016).

Fire Hazard (Non-Wildland/Operational)

Fire prevention and suppression methods are proposed as part of the Project's design. To protect the battery system, a fire suppression system (FSS) will be installed in the container (Phase 1) and building (Phase 2), and employs FM200 gas agent along with smoke detectors, control panel, alarm, piping and nozzles. These features are described in greater detail under Impact 4.5.2 below.

Valley Fever

Construction of the proposed project would occur in an area favorable to the growth of Valley Fever, a fungus (*Coccidioides immitis*) that grows in soils in areas of low rainfall, high summer temperatures, and moderate winter temperatures. Project construction would disturb the soil and cause the fungal spores to become airborne, potentially putting construction personnel and wildlife at risk of contracting Valley Fever. However, Imperial County is not considered to have a high incidence of Valley Fever (BLM 2011). While the potential exposure of workers to Valley Fever spores could occur during construction, implementation of a Dust Control Plan and the provisions of Regulation VIII identified to reduce PM_{10} in Section 4.1, Air Quality/Greenhouse Gas Emissions would be effective in reducing airborne dust. Implementation of these measures, as well as a Dust Control Plan as required by the Imperial County Air Pollution Control District, would minimize the spread of fungal spores thereby reducing potential for contracting Valley Fever during construction. No impacts associated with exposure to Valley Fever are anticipated during operations and maintenance given that earthmoving is proposed and vehicles would be driven on paved and gravel covered roadways thereby minimizing dust levels.

D. METHODOLOGY

The analysis of hazardous materials is twofold: those potentially existing on the site and those that would be used as part of Project construction, operations and maintenance, and decommissioning.

Some hazardous materials would be used on a short-term basis during construction and decommissioning. Others would be stored on-site for use during operations and maintenance similar to those currently in use as part of operation of the Substation. Therefore, this analysis was conducted by examining the types and amount of chemicals to be used, the manner in which the Applicant would use the chemicals, the manner by which they would be transported to the facility, and the way in which the Applicant plans to store the materials on site.

E. PROJECT IMPACTS AND MITIGATION MEASURES

Hazardous Materials Transport, Use, Disposal and Accidental Release

Impact 4.5.1 The proposed Project would involve the transport, use, and disposal of hazardous materials in association with construction, operation and decommissioning. However, all materials would be transported, used and disposed of in accordance with all applicable local, state and federal requirements. Therefore, impacts associated with accidental release during hazardous materials transport, use and disposal are considered **less than significant**.

Transport

Some hazardous materials would be required during construction, operations and maintenance, and decommissioning of the proposed Battery Energy Storage System. These include diesel fuel, oil and grease for heavy equipment as well as paints and solvents. Large quantities of these materials are not anticipated to be necessary but would require transport to the Project site. Hazardous materials such as diesel fuel, oil and grease for heavy equipment, would be transported to the site during construction and decommissioning. Materials containing electrolyte and graphite would also be transported during construction, operation (if replacement of batteries is needed) and decommissioning (removal of the batteries). All of these various materials would be transported and handled in compliance with Department of Toxic Substances Control (DTSC) regulations. Therefore, likelihood of an accidental release during transport or residual contamination following accidental release is not anticipated. Thus, less than significant impacts are anticipated in association with transport, use, disposal and accidental release of hazardous materials during construction, operation and decommissioning of the proposed Project.

Use and Storage

A variety of hazardous materials would be used during construction and decommissioning of the proposed Project including diesel, gasoline, motor oil and hydraulic fluids and lube oils for vehicles and equipment, and mineral oil for transformers. However, no acutely toxic hazardous materials would be used and none of the materials are anticipated to pose a significant potential for off-site impacts such as contamination through a large release of chemicals. Spill containment and clean-up kits will be kept on site during construction, operation and decommissioning of the Battery Energy Storage System. In addition, the Project will also be required to comply with State laws and County Ordinance restrictions, which regulate and control hazardous materials handled on-site. Therefore, potential for accident conditions involving the release of hazardous materials used or stored during construction and decommissioning is considered a **less than significant impact**

Lithium ion batteries contain cobalt oxide, manganese dioxide, nickel oxide, carbon, electrolyte, and polyvinylidene fluoride. Only the electrolyte should be considered hazardous (inflammable, and could react hazardously if mixed with water). The electrolyte solvent is a mix of three organic solvents with the following characteristics:

	Solvent 1	Solvent 2	Solvent 3
	Temperature (degrees Celsius)		
Boiling Point[1]	248	107	90.5
Flash Point[2]	145.5	23.5	16
Class[3]	III-B	I-C	I-B

Source: Southern Power Company 2016.

1 The **boiling point** of a substance is the temperature at which the vapor pressure of the liquid equals the pressure surrounding the liquid and the liquid changes into a vapor.

2 The **flash point** of a flammable liquid is the lowest temperature at which there will be enough flammable vapor to ignite when an ignition source is applied.

3 Rules for Flammability Class:

- Class I-A flammable liquids have a flash point below 73 °F (22.8 °C) (the upper end of the common range of room temperature) and a boiling point below 100 °F
- Class I-B flammable liquids have a flash point below 73 °F (22.8 °C) and a boiling point greater than or equal to 100 °F (37.8 °C)
- Class I-C flammable liquids have a flash point greater than or equal to 73 °F (22.8 °C) and below 100 °F (37.8 °C)
- Class II combustible liquids have a flash point greater than or equal to 100 °F (37.8 °C) and below 140 °F (60 °C)
- Class III-A combustible liquids have a flash point greater than or equal to 140 °F (60 °C) and below 200 °F (93.3 °C)
- Class III-B combustible liquids have a flash point greater than or equal to 200 °F (93.3 °C)

As shown, each of the solvents have differing boiling points and flash points. Solvent 1 is a combustible liquid whereas Solvent 2 and 3 are flammable liquids. Solvent 1 requires a very high temperature flash point in order to combust. Solvent 2 and 3 have lower flash and boiling points before they will ignite. As previously noted, electrolyte only becomes flammable in the presence of water.

In addition to the electrolyte solvent in the presence of water, the carbon, which is graphite, is also flammable. Fire risk factors would be mitigated through project design features including monitoring, diagnostics and by a fire suppression system. The batteries for both Phase 1 and Phase 2 are in enclosed facilities. The container for Phase 1 and the building for Phase 2 serve to provide fire protection as well as to mitigate the risk of potential spills. The Project will also be required to comply with State laws and County Ordinance restrictions which regulate and control hazardous materials handled on-site. Therefore, potential for accident conditions as part of use and storage during construction, operation and decommissioning of the Battery Energy Storage System is considered a **less than significant impact**.

Disposal

During construction, typical construction wastes such as wood, concrete, and miscellaneous packaging materials would be generated. Construction wastes will be disposed of in accordance with local, State and federal regulations, and recycling will be used to the greatest extent possible. Left-over or spent materials such as used hydraulic fluid, oils, and grease would be generated during Project construction. Any spent or surplus hazardous wastes would be transported off-site for disposal according to applicable State and County restrictions and laws governing the disposal of hazardous waste. The same would occur with regard to any used or spent hazardous materials requiring disposal during operation.

In the event that cell damage is suspected and requires replacement or removal during construction, operation and/or decommissioning, Samsung SDI's Customer Service Team and Southern Power Company's Return Merchandise Authorization service provider, CKS, will assist in removal of affected equipment. Recycling of the battery cells is also performed by CKS (Southern Power Company 2016). The batteries will be transported/shipped in compliance with all applicable federal, state and local regulations addressing hazardous materials transport. Once the batteries arrive at their destination, the old cells are opened, and the major components (electrolyte, electrode, current collector foils, case) are separated and repurposed. With adherence to these procedures, the potential for accident conditions involving the release of hazardous materials disposed of during construction, operation and decommissioning is considered a **less than significant impact**.

<u>**Mitigation Measures**</u>

None required.

<u>**Significance After Mitigation**</u>

Not applicable.

Hazard Through Upset/Release of Hazardous Materials

Impact 4.5.2 The proposed Project site was historically farmed but is now part of the Campo Verde Solar Project. The Phase I ESA prepared for the Campo Verde Solar Project did not identify the use of pesticides as a Recognized Environmental Condition. The Project as proposed includes safety features to reduce potential for leaks and fires. Therefore, impacts through upset/release of hazardous materials are considered **less than significant**.

Herbicides/Pesticides

The Project site has historically been farmed but is now within the boundaries of the Campo Verde Solar Project. The Phase I ESA did not identify the use of pesticides as a Recognized Environmental Condition (REC) as no mixing or storage of large quantities of pesticides was identified during the reconnaissance of the Campo Verde Solar Project site or during the review of historical data and/or regulatory databases (Ray 2011). Based on the historical agricultural use of the property, the Phase I ESA acknowledged that there is the potential for residual pesticide concentrations in the surface and subsurface soils (URS 2012, p. 2-5). However, the Phase I ESA did not recognize this as a REC. While chemical retention in surface and subsurface soils could be of concern, the majority of agricultural chemicals degrade rapidly in the presence of ultraviolet light from the sun. Further, most newer-formulated chemicals have lower retention time especially at the lower application concentrations directed by regulatory agencies. No soil remediation was recommended.

The application of herbicides and pesticides on site would have been controlled by the applicators as directed by the Federal Insecticide, Fungicide, and Rodenticide Act (“FIFRA”) in accordance with manufacturer prescribed and labeled instructions. Therefore, the potential presence of low concentrations of agricultural chemicals on the Project site is not anticipated to be at hazardous levels. Also, the proposed Battery Energy Storage System does not include a residential or commercial component that would result in long-term exposure of people to potential pesticides/herbicides. Therefore, no direct impact (exposure during construction and decommissioning) or indirect impact (exposure following construction during operations and maintenance) would occur relative to pesticide residue in association with construction of the proposed Project.

Currently, herbicides are used at the neighboring Substation to control weeds as prescribed in the Integrated Pest Management Plan for Private Lands Campo Verde Solar Project (Heritage 2012c). The potential for air dispersion of pesticide or herbicide residues in dust during grading activities for the Battery Energy Storage System would be minimized by the fugitive dust control plan implemented by the Applicant in accordance with Imperial County Air Pollution Control District (ICAPCD) requirements. Compliance with ICPACD Regulation VIII, Fugitive Dust Rules, would prevent, reduce, or mitigate the PM_{10} emissions (ICAPCD 2006). Specifically, compliance with Rule 801-Construction and Earthmoving Activities, Rule 805-Paved and Unpaved Road, and Rule 806-Conservation Management Practices would reduce PM_{10} emissions, minimize dust and also reduce any associated air dispersal of pesticide residues. Therefore, impacts associated with hazard through upset/release of hazardous materials resulting from exposure to pesticide residue and herbicides during construction, operation and decommissioning are considered **less than significant**.

Risk of Fire

Lithium ion batteries are technology proposed to store energy on the Campo Verde Solar Project site. Specifically, a Samsung SDI Energy Storage System (ESS) will be used. Phase 1 will include 440 modules and 13,200 batteries housed in a metal modular battery system container on a concrete foundation. The container will be cooled with two HVAC units. Phase 2 batteries will include 8,800 modules and 264,000 batteries housed in a metal building on a concrete foundation. This container will be cooled by eight HVAC units (Southern Power Company 2016).

The Samsung SDI ESS includes multiple safety designs to minimize risk of fire. The battery modules have been subjected to the “Internal Fire Exposure Test” by Underwriter’s Laboratory to demonstrate that they are not susceptible to thermal runaway (i.e. failure of a single cell within the system will not cascade into a fire and explosion) (Samsung n.d.).

An added level of protection is included in as part of Project design by housing the battery units in enclosed structures to provide containment should a fire break out. In addition, housing the battery units in an enclosure also mitigates the risk of potential spills.

Design Features to Reduce Risk of Fire

Monitoring

Lithium ion batteries present a risk of fire primarily if overcharged. To avoid risk of fire, overcharging will be monitored and prevented through several levels of safety in the diagnostic system. Likewise, end of life replacement will be detectable through monitoring and notice to replace batteries (Southern Power Company 2016).

Fire Suppression System

To protect the battery system from risk of fire, the FM 200 Fire Suppression System (FSS) or comparable will be installed in the Phase 1 container and Phase 2 building (Southern Power 2016). The FSS employs FM-200 or comparable gas agent along with smoke detectors, control panel, alarm, piping and nozzles. FM-200 is a clean, colorless, and environmentally friendly fire suppression agent that is electrically non-conductive. FM-200 or comparable fire extinguishing systems are designed to be discharged within a room, area, or enclosure with the structural integrity to retain the agent. The system extinguishes flames primarily through heat absorption, leaving no residue, thus minimizing downtime after a fire.

The FM-200 Fire Suppression System includes the following:

- FM-200 Storage Components or comparable – Storage components consist of the cylinder assembly(s), which contains the FM-200 chemical agent.
- FM-200 Distribution Components or comparable – Distribution components consist of the discharge nozzles used to introduce the FM-200 into an associated piping system used to connect the nozzles to the cylinder assembly.
- Control Panel – This device monitors the condition of the electric actuator, detectors, warning devices, cylinder pressure, and any manual release and abort stations.
- Early Warning Detection and Alarm Devices – Early warning detection devices coupled with manual release and abort stations maximize system efficiency while audible and visual alarm devices alert staff of alarm conditions.

A fire suppression system agreed upon by Imperial County will be installed to extinguish possible ignition.

Implementation of the Project design features, coupled with the Samsung SDI ESS, will reduce impacts associated with hazard through upset/release of hazardous materials resulting from risk of fire during operation to **less than significant**.

2013 California Fire Code Requirements

In addition to the fire safety mechanisms included as part of design of the Battery Energy Storage System, the ICFD was consulted to provide input on the Project. As part of the ICFD's initial review, the following items were set forth as requirements for the Phase 1 container and the Phase 2 building in accordance with the 2013 CFC.

Phase 1

503.1 Where required. Fire apparatus access roads shall be provided and maintained in accordance with sections 503.1.1 through 503.1.3.

503.1.1 Buildings and facilities. Approved fire apparatus access road shall be provided for every facility, building or portion of a building hereafter constructed or moved into or within the jurisdiction. The fire apparatus access road shall comply with the requirement of this section and shall extend to within 150 feet (45,720 mm) of all portion of the facility and all portions of the exterior wall of the first story of the building as measured by an approved route around the exterior of the building or facility.

503.2.1 Dimensions. Fire apparatus access roads shall have an unobstructed width of not less than 20 feet (6,096 mm), exclusive of shoulder, except for approved security gate in accordance with Section 503.6, and an unobstructed vertical clearance of not less than 13 feet 6 inches (4,115 mm).

503.2.3 Surface. Fire apparatus access road shall be designed and maintained to support the imposed load of fire apparatus and shall be surfaced so as to provide all weather driving capabilities.

608.7 Signage. Signs shall comply with Sections 608.7.1 and 608.7.2.

608.7.1 Equipment room and building signage. Doors into electrical equipment rooms or buildings containing stationary battery systems shall be provided with approved signs. The sign shall state that: 1. The room contains energized battery systems. 2. The room contains energized electrical circuits. 3. The battery electrolyte solutions, where present, are corrosive liquids.

608.7.2 Cabinet signage. Cabinets shall have exterior labels that identify the manufacturer and model number of the system and electrical rating (voltage and current) of the contained battery system. There shall be signs within the cabinet that indicate the relevant electrical, chemical and fire hazards.

608.8 Seismic protection. The battery systems shall be seismically braced in accordance with the California Building Code.

608.9 Smoke detection. An approved automatic smoke detection system shall be installed in accordance with Section 907.2 in rooms containing stationary battery systems.

906.1 Where required. Portable fire extinguishers shall be installed in the following locations.

1. In new and existing Group A, B, E, F, H, I, L, M, R-l, R-2 R-2.1, R-3.1, R-4 and S occupancies.

6. Special-hazard areas, including but not limited to laboratories, computer rooms and generator rooms, where required by the fire code official.

907.2 Where required, new buildings and structures. An approved fire alarm system installed in accordance with the provisions of this code and NFP A 72 shall be provided in new building and structures in accordance with Sections 907.2.1 through 907.2.23 and provide occupant notification in accordance with Section 907.5, unless other requirements are provided by another section of this code.

907.2.23 Battery rooms. An automatic smoke detection system shall be installed in areas containing stationary storage battery systems with a liquid capacity of more than 50 gallons (189 L).

Phase 2

All items required for the Phase 1 battery storage container in accordance with the 2013 CFC will also be required for the Phase 2 building with addition of the following requirements:

903.1 General. Automatic sprinkler systems shall comply with this section.

903.1.1 Alternative protection. Alternative automatic fire-extinguishing systems complying with Section 904 shall be permitted in lieu of automatic sprinkler protection where recognized by the applicable standard and approved by the fire code official.

903.2 Where required. Approved automatic sprinkler systems in new buildings and structures shall be provided in the locations described in Sections 903.2.1 through 903.2.12.

903.2.9 Group S-l. An automatic sprinkler system shall be provided throughout all buildings containing a Group S-l occupancy where one of the following conditions exists:

1. A Group S-l fire area exceeds 12,000 square feet 1,115 square meters.

904.1 General. Automatic fire-extinguishing systems, other than automatic sprinkler systems, shall be designed, installed, inspected, tested and maintained in accordance with the provisions of this section and the applicable referenced standards.

904.2 Where required. Automatic fire-extinguishing systems installed as an alternative to the required automatic sprinkler systems of Section 903 shall be approved by the fire code official. Automatic fire-extinguishing systems shall not be considered alternatives for the purposes of exceptions or reductions allowed by other requirements of this code.

The required minimum is based off the 2013 CFC and Imperial County ordinances on rural water supply for firefighting (Loper 2016).

Compliance with the requirements of the 2013 CFC will reduce impacts associated with hazard through upset/release of hazardous materials resulting from risk of fire during operation to **less than significant**.

Battery Storage and Handling

The chemical composition of the lithium ion batteries includes cobalt oxide, manganese dioxide, nickel oxide, carbon, electrolyte, polyvinylidene fluoride, aluminum foil; copper foil, aluminum and inert materials. Only the electrolyte could react hazardously if mixed with water and carbon, which is graphite, and is also flammable. The operational crews would be trained on how to properly and safely handle the batteries with the proper personal protective equipment (PPE) based upon the material safety data sheets (MSDS) of the batteries.

Batteries removed from service will be returned to the manufacturer for recycling. In the event that cell damage is suspected, Samsung SDI's Customer Service Team and RMA service provider, CKS, will assist in removal and recycling of the affected equipment.

Applicable codes and standards for the storage and handling of lithium ion batteries are included in Chapter 6, Section 608 Stationary Storage Battery Systems of the 2013 CBC. Compliance with all applicable codes and standards as well as the 2013 CFC will reduce impacts associated with hazard through upset/release of hazardous materials resulting from battery storage and handling during construction, operation and decommissioning to **less than significant**.

<u>Mitigation Measures</u>

None required.

<u>Significance After Mitigation</u>

Not applicable.

4.5.4 CUMULATIVE SETTING, IMPACTS AND MITIGATION MEASURES

A. CUMULATIVE SETTING

The geographic scope of the cumulative setting for hazards and hazardous materials is a one-mile radius around the Project site. One mile is the standard American Society of Testing and Materials (ASTM) standard search distance for hazardous materials. This geographic scope encompasses an area larger than the Project site and provides a reasonable context wherein cumulative projects in the vicinity of the proposed Project could affect hazards and hazardous materials. Based on Table 3.0-1 (Past, Present and Probable Large-Scale Solar Projects in the vicinity of the Battery Energy Storage System) in Chapter 3.0, Introduction to the Analysis and Assumptions Used, no other cumulative project from the list is within the geographic scope.

B. CUMULATIVE IMPACTS AND MITIGATION MEASURES

Cumulative Hazards and Hazardous Materials Impact

Impact 4.5.3 The proposed Battery Energy Storage System, in combination with other Past, Present and Probable Large-Scale Projects in the vicinity of the Campo Verde Battery Energy Storage System, would not increase the density of development in the area because no other cumulative projects are within the cumulative geographic scope. Thus, the proposed Project's contribution to cumulative hazards and hazardous materials impacts is considered **less than cumulatively considerable**.

None of the cumulative projects shown on Figure 3.0-1 in Chapter 3.0 are within a one-mile radius of the Project site. Accordingly, none of the cumulative projects are within the geographic scope for the consideration of cumulative effects from hazardous materials sites.

Potential for risk of upset is localized and site specific. Potential fire risk impacts are not expected to combine with similar impacts of past, present and probable large-scale solar projects in the vicinity of the Campo Verde Battery Energy Storage System. The Project includes design features to minimize the impacts of the proposed Battery Energy Storage System relative to hazards and hazardous materials. In addition, the Project is required to comply with the 2013 CFC as well as all applicable codes and standards. With implementation of the proposed design features and compliance with applicable codes and standards, Project impacts to hazards and hazardous materials would be less than significant. Likewise, the Project's contribution to cumulative hazardous materials impacts is **considered less than cumulatively considerable**.

Mitigation Measures

None required.

Significance After Mitigation

Not applicable.

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