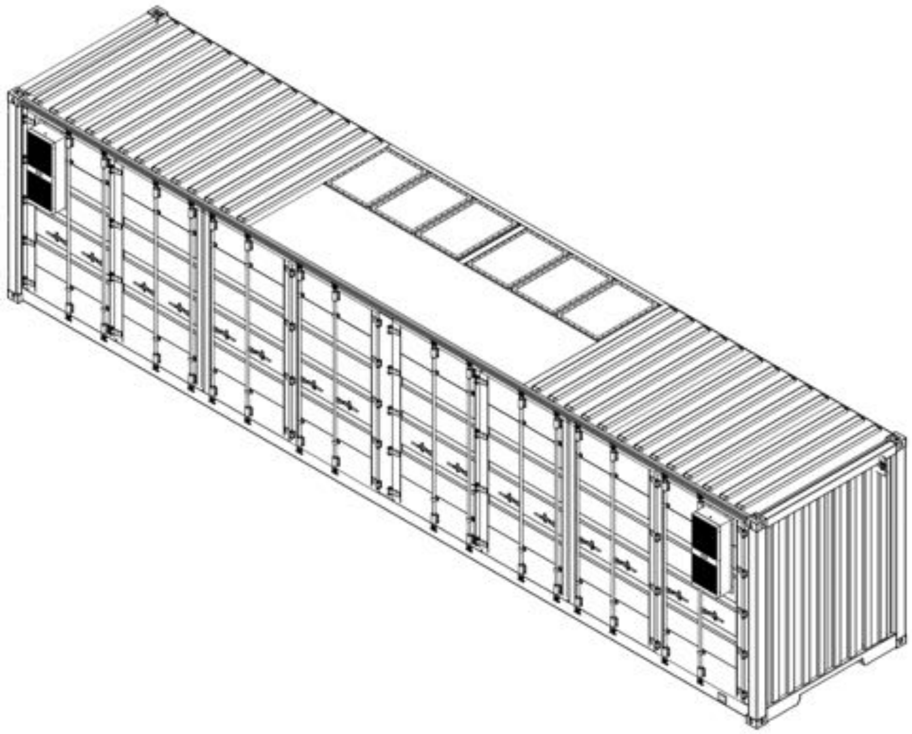
Exhibit 1

Draft Preliminary HMA Report

Rancho Viejo Solar Utility BESS

August 13, 2024
Revision A



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Draft Preliminary HMA

Rancho Viejo

August 13, 2024
Revision A

Coffman Project Number: 241470

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Revision History		
Revision	**Date**	**Description of Revision**
A	7/24/2024	Preliminary HMA 1St Draft
A1	8/13/2024	Preliminary HMA Revised Draft

EXECUTIVE SUMMARY

This Hazardous Mitigation Analysis (HMA) evaluates the conformance of the AES Rancho Viejo Solar Utility Battery Energy Storage System (BESS) project site with respect to the HMA requirements of NFPA 855, *Standard for the Installation of Energy Storage Systems* and IFC, *International Fire Code*.

ANALYSIS FAILURE MODES

The failure modes considered in this analysis are based on the specific failure modes required to be evaluated when completing an HMA per the 2021 edition of IFC and the 2023 edition of NFPA 855. The failure modes analyzed are as follows and discussed further in Appendix A for how they directly correspond to the failure modes within the two codes:

1. A thermal runaway or mechanical failure in a single ESS unit.
2. Failure of an energy storage management system or protection system that is not covered by the product listing failure modes and effects analysis.
3. Failure of a required protection system including, but not limited to, ventilation (HVAC), exhaust ventilation, smoke detection, fire detection, fire suppression, or gas detection.
4. Voltage surges on the primary electric supply.
5. Short circuits on the load side of the ESS.

ANALYSIS ACCEPTANCE CRITERIA

The acceptance criteria used in this analysis aligns to the HMA approval criteria listed in the 2021 edition of IFC and the 2023 edition of NFPA 855. The acceptance criteria applied in this analysis is described below and in further detail in Appendix A for how it directly corresponds to the criteria within the two codes:

1. Fires and products of combustion will not prevent occupants from evacuating to a safe location.
2. Deflagration hazards will be addressed by an explosion control or other system.

ANALYSIS APPROACH

This evaluation implements a bowtie methodology to holistically evaluate the CEN BESS enclosure against the identified acceptance criteria. This hazard model follows the guidance provided in NFPA 855 Section G.4. Bow tie modeling is a common hazard mitigation analysis tool used in the maritime, oil and gas, and utility industries. The strength of the bowtie approach comes from its visual nature, which evaluates the chronological pathways leading from threats to critical hazard events to consequences with the associated mitigative and preventative barriers in place to reduce or eliminate the said consequences.

ANALYSIS APPROVAL

Demonstration of conformance with the acceptance criteria is as described below:

1. Fires and products of combustion will not prevent occupants from evacuating to a safe location.

   The CEN enclosure features a sufficient quantity of safety barriers to limit the rate of propagation of an escalating fire or thermal runaway event and provide adequate situational awareness to facility occupant to permit evacuation to a safe location.

2. Deflagration hazards will be addressed by an explosion control or other system.

   This analysis has identified that a propagating cell failure event poses a deflagration hazard. The CEN enclosure will be equipped with a NFPA 68 compliant deflagration venting system to release *the combustion gases and pressure resulting from a deflagration within the enclosure so that structural and mechanical damage is minimized.*

Conformance with acceptance criteria described above is intended to demonstrate compliance with the HMA requirements of NFPA 855 and the IFC.

MAJOR ANALYSIS ASSUMPTIONS AND LIMITATIONS

This hazard study documented in this report is subject to the following major assumptions and limitations:

- **Unknown Failure Modes** – Major BESS failures modes not known by industry at the time of this analysis and not otherwise considered in this report may exist.
- **Outside Event effecting more than one unit** – The compounding effect of failure modes affect more than one enclosure at a time is not directly considered.
- **Hazards during Construction, Shipping and Storage** – The hazards associated with the construction, off-site storage and shipping of the BESS enclosures are not evaluated.
- **Continued Maintenance** – All BESS systems are assumed to be inspected, tested and maintained to minimum standards.
- **Installed per code** – Protection systems inside the BESS enclosure and site wide protection systems are assumed to be installed and maintained per minimum regulatory requirements. Coffman is not scoped to verify code compliance within the BESS enclosure.

TABLE OF CONTENTS

ABBREVIATIONS AND ACRONYMS

AC	Alternating Current
AES	AES Clean Energy
AHJ	Authority Having Jurisdiction
BESS	Battery Energy Storage System
BCU	Battery Control Unit
BMS	Battery Management System
CID	Current Interrupt Device
DC	Direct Current
ESS	Energy Storage System
FACP	Fire Alarm Control Panel
FEMA	Failure Modes and Effects Analysis
HMA	Hazard Mitigation Analysis
HRR	Heat Release Rate
HVAC	Heating, Ventilation & Air Conditioning
IDLH	Immediately Dangerous to Life or Health
IFC	International Fire Code
IP	Ingress Protection
LFL	Lower Flammability Limit
NFPA	National Fire Protection Association
PLC	Programmable Logic Controller
ROCC	Remote Operations Control Center
SCADA	Site Supervisory Control and Data Acquisition
SME	Subject Matter Expert
SOC	State of Charge
SOH	State of Health
UPS	Un-interruptible Power Supply
VRLA	Valve-Regulated Lead Acid

1.0 INTRODUCTION

This Hazard Mitigation Report has been prepared by Coffman Engineers, Inc. (Coffman) to evaluate the conformance of the AES Rancho Viejo Solar Utility Battery Energy Storage System (BESS) project site against the Hazardous Mitigation Analysis (HMA) requirements of the National Fire Protection Association (NFPA) 855, *Standard for the Installation of Energy Storage Systems* (2023 edition), and the *International Fire Code* (2021 edition). This evaluation assesses the anticipated overall effectiveness of the provided protective barriers to prevent and mitigate the consequences of a battery related failure.

This analysis is based on conversations with AES Clean Energy (AES) personnel as well as the provided drawings and documents listed in the Referenced Documents section at the end of this report.

1.1 APPLICABLE CODES AND STANDARDS

This analysis evaluates the AES Rancho Viejo Solar Utility site against the requirements found in the codes and standards referenced below:

- *International Fire Code* (IFC), 2021 edition, as adopted by Sante Fe County Ordinance 2023-06
- *Sante Fe County Ordinance 2023-06 as adopted by the Board of County Commissioners*
- *Sante Fe County Ordinance 2023-09 as adopted by the Board of County Commissioners*
- *International Wildland Urban-Interface Code* (IWUIC), 2021 edition, as adopted by Sante Fe County
- NFPA 855, *Standard for the Installation of Energy Storage System*, 2023 edition
- NFPA 68, *Explosion Protection by Deflagration Venting*, 2013 edition
- NFPA 72, *National Fire Alarm and Signaling Code*, 2019 edition
- NFPA 2001, *Standard on Clean Agent Fire Extinguishing Systems*, 2018 edition
- UL 9540A, *Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems*, 4^{th} Edition, November 12, 2019

1.2 OTHER REFERENCED CODES, STANDARDS AND RECOMMENDED PRACTICES

The following industry standards and recommended practices are referenced throughout this report in addition to the adopted codes and standards referenced above.

- ISO IEC 31010, *Risk Assessment Techniques*, 2019 edition

1.3 ANALYSIS GOALS AND OBJECTIVES

In accordance with NFPA 855 Section 9.4.1 and IFC Section 1207.5, an approved HMA is required to permit outdoor lithium-ion Energy Storage Systems (ESS) installations with a capacity exceeding 600 kWh. The objective of this HMA is to evaluate the consequences of the site-specific failure modes.

The single mode failure modes considered in this analysis are described in Table 1, below. The failure modes described in the table align to the single mode failure modes listed in the 2023 edition of NFPA 855 and the 2021 editions of the IFC. See Appendix A for a detailed description of how the selected failure modes correlate to specific IFC and NFPA 855 requirements.

Table 1: Analysis Failure Modes	
Failure Mode	**Failure Mode Description**
1	A thermal runaway or mechanical failure in a single ESS unit.
2	Failure of an energy storage management system or protection system that is not covered by the product listing failure modes and effects analysis (FMEA).
3	Failure of a required protection system including, but not limited to, ventilation (HVAC), exhaust ventilation, smoke detection, fire detection, fire suppression, or gas detection.
4	Voltage surges on the primary electric supply.
5	Short circuits on the load side of the ESS.

The acceptance criteria applied in this analysis is described in Table 2. The acceptance criteria described in the table aligns to the HMA approval criteria listed in the 2023 edition of NFPA 855 and the 2021 edition of the IFC. See Appendix A for a detailed description of how the selected acceptance criteria correlate to specific IFC and NFPA 855 requirements.

Table 2: Analysis Acceptance Criteria	
Acceptance Criteria	**Acceptance Criteria Description**
1	Fires and products of combustion will not prevent occupants from evacuating to a safe location
2	Deflagration hazards will be addressed by an explosion control or other system

2.0 SITE DESCRIPTION

2.1 SITE INFORMATION

The AES-Rancho Viejo Solar Utility BESS project site is located in Santa Fe County, New Mexico. A site plan of the battery energy storage system layout is shown in **Figure 1**.

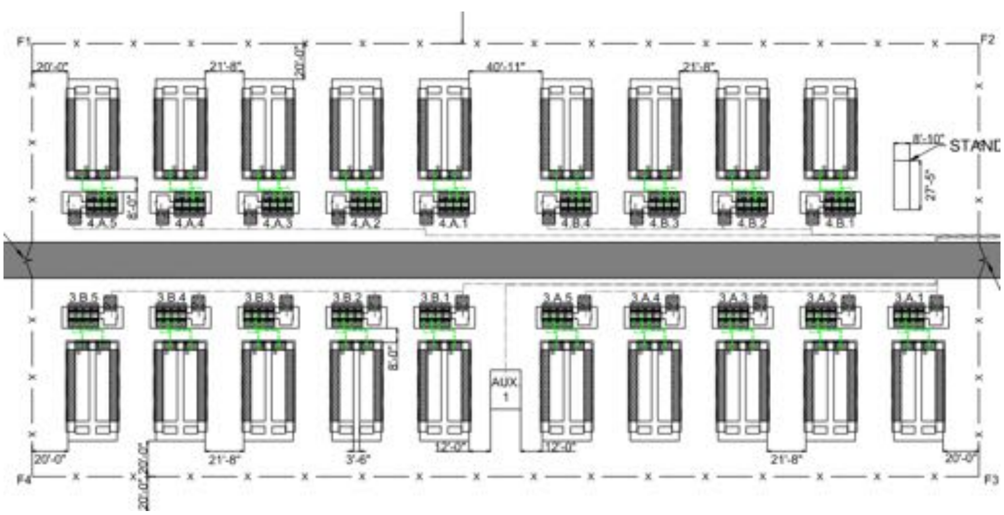

Figure 1 - Rancho Viejo BESS Site Plan

The site will include CEN enclosures manufactured by AES containing lithium-ion battery technology. The energy storage system proposed for this project is the Samsung SDI / E5S ESS. The details of the Rancho Viejo BESS facility are summarized in Table 3 below.

Table 3: CEN BESS System Specification Summary	
Owner:	AES
Overall BESS Capacity:	48 MW for 4 hours / 192 MWh
Number of BESS Enclosures:	38
Total Site Area:	2.94 Acres

2.2 FIRE DEPARTMENT ACCESS

Fire department roads will be provided on site to meet the spatial criteria of the IFC as noted below and shown in **Figure 2**:

- Unobstructed width of at least 20 feet
- Unobstructed vertical clearance of 13 feet 6 inches
- Dead ends more than 150 feet will be provided with an approved turn around area

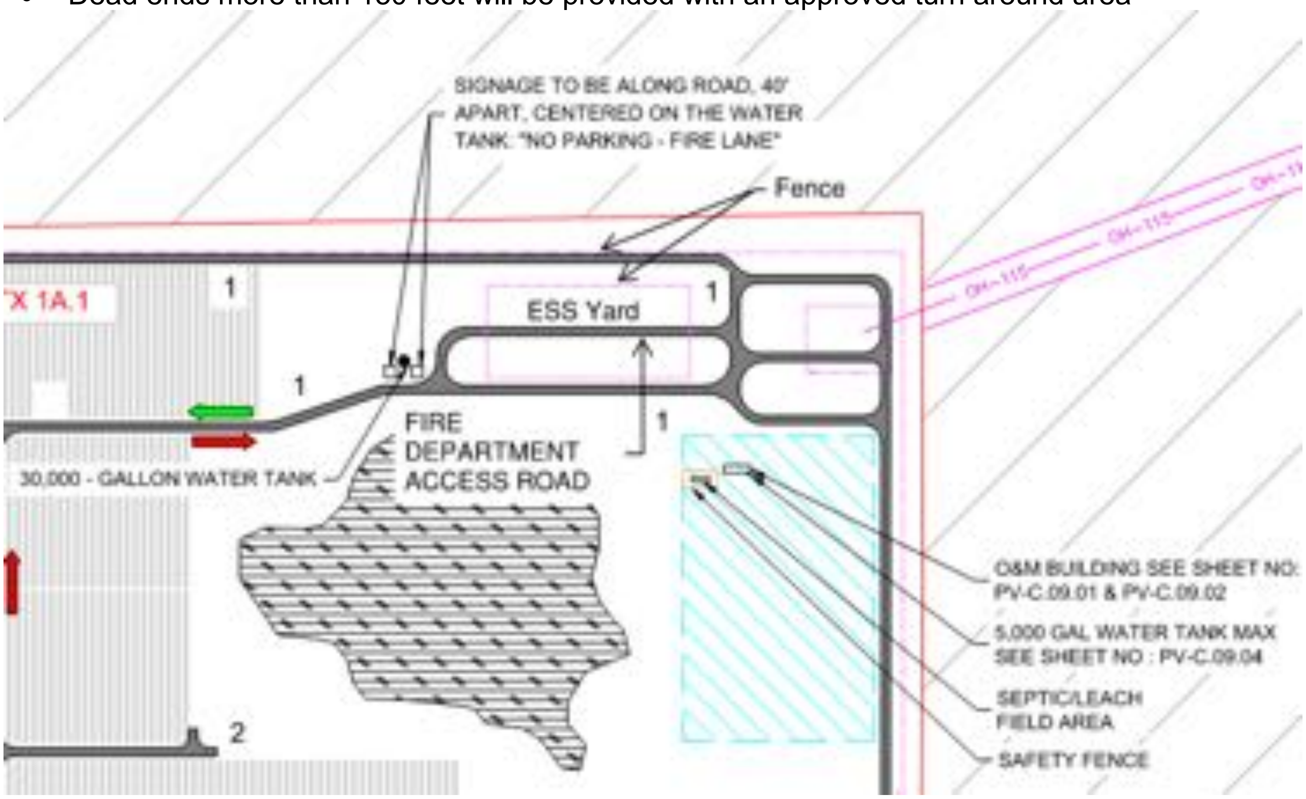

Figure 2 - Fire Department Features Site Map

2.3 LOCAL CLIMATE CONDITIONS

ASHREA data for the nearest airport at Albuquerque International shows a 1% extreme wind speed of 28.2 mph and 0.4% annual occurrence high temperature of 95.2º F. The overall site is relatively flat and does not pose additional risks.

3.0 ENERGY SYSTEM DESCRIPTION

The CEN enclosure is an 8,068 kWh lithium-ion BESS. The CEN enclosure utilizes lithium-ion cells manufactured by Samsung featuring lithium nickel cobalt aluminum oxide chemistry. The CEN enclosure is a non-walk-in style ground mounted outdoor BESS enclosure. Primary equipment included within the enclosure includes lithium-ion battery modules, DC disconnect switch, control and communications panel, AC/DC electrical panel, dehumidifiers, chilled water-cooling lines, and a fire suppression system. An image of the CEN enclosure is shown in Figure 3 – CEN BESS Enclosure (Exterior View)and Figure 4, below. The CEN enclosure specifications are summarized in Table 4.

Table 4: E5S BESS System Specification Summary

ESS System Manufacturer:	AES
ESS Model #:	AES Spec CEN-E5S
ESS Electrical Ratings:	8,068 kWh
ESS Max Voltage:	1494 Vdc
ESS Enclosure Dimensions:	40'-0" (L) x 8'-0" (W) x 9'-6" (H)
ESS Layout / Construction:	Non-Occupiable, Non-Walk-in, Non-Combustible 252 Modules per enclosure

Cell		**Module**	
Manufacturer:	Samsung SDI CO LTD	Manufacturer:	Samsung SDI CO LTD
Model No:	CP1495L101A	Model No:	E5S (MS3204L101A)
Electrical Rating:	3.68 Vdc, 145 Ah	Electrical Rating:	110.4 Vdc, 290 Ah
Chemistry:	$LiNiCoALO_2$	Cells per Module:	60
Format:	Prismatic	Module Dimensions:	388 x 1751 x 155 mm

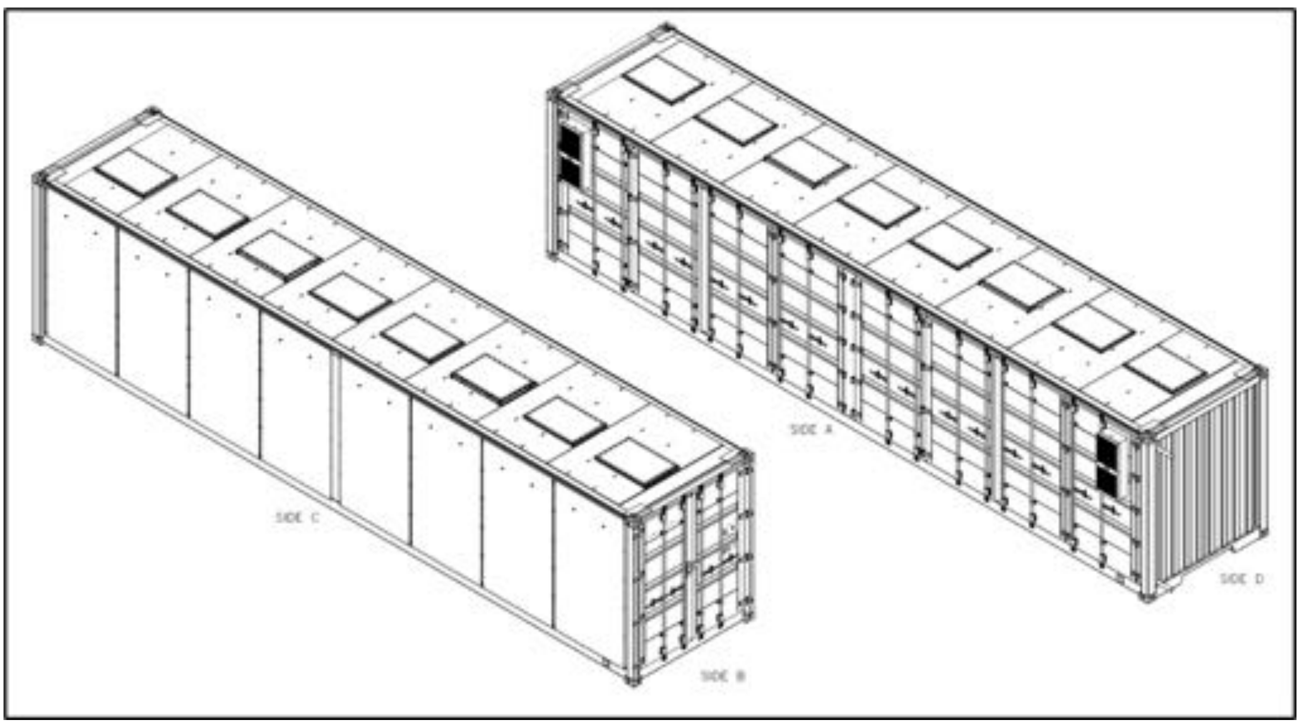

Figure 3 – CEN BESS Enclosure (Exterior View)

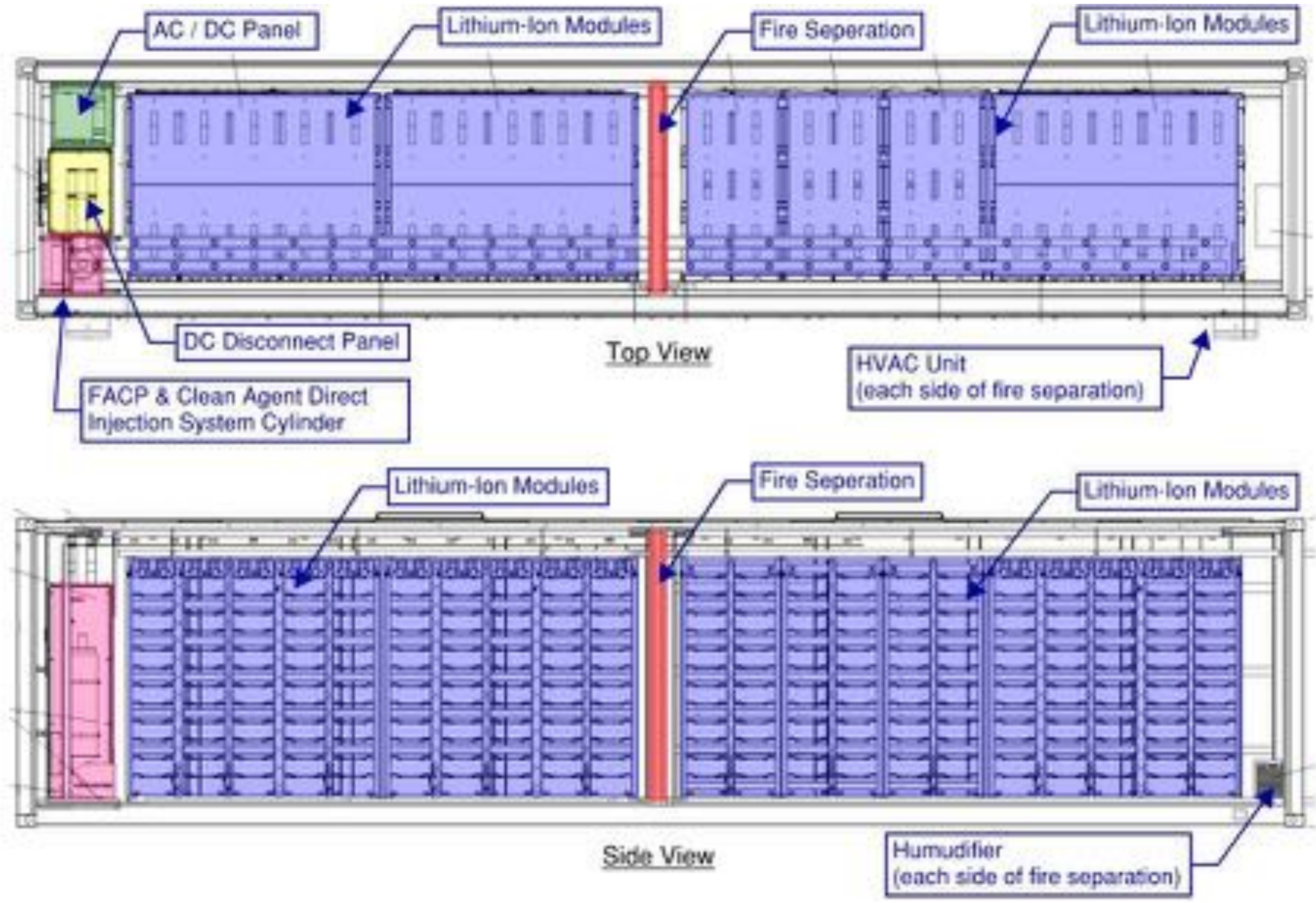

Figure 4 – CEN BESS Enclosure (Internal View)

3.1 ESS ENCLOSURE AND EQUIPMENT DESCRIPTION

The CEN enclosure consists of a 40'-0" long x 8'-0" wide x 9'-6" high, IP 55 rated, ISO container (See Figure 3). The enclosure features openable doors three sides. Deflagration panels are provided on the enclosure roof. The enclosure is subdivided by a fire separation constructed utilizing a metal faced mineral wool panel. The ceiling, wall and door panels are equipped with an FM Global approved Class 1 insulation material.

The enclosure contains 252 lithium-ion battery modules, each containing 60 cells. The modules are located on racks as shown in Figure 4. Each battery rack includes 12 battery modules and a battery control unit (BCU). The BCU contains the battery management system (BMS), contactor and fuse for the respective battery rack.

A DC disconnect switch panel containing the main DC fuses and disconnect switch is located on side B of the enclosure (See Figure 4). Also located on side B of the enclosure is an AC/DC electrical panel and an 1800 W un-interruptible power supply (UPS). The UPS is equipped with valve-regulated lead acid (VRLA) batteries. The fire alarm control panel (FACP) and fire suppression tank are also located in this area.

The enclosure is provided with humidifier and externally mounted HVAC units. Heating within the enclosure is provided by electric resistance heating. Cooling to the battery modules is provided by a liquid cooling system connected to a remote external chiller. The cooling system utilizes a 50/50 ethylene glycol mixture. No flammable refrigerants will be used within the enclosure.

3.2 FIRE AND THERMAL RUNAWAY SAFETY FEATURES

The CEN enclosure will include the following fire and thermal runaway features.

3.2.1 Battery Management System

The CEN enclosure includes an integrated BMS. The BMS system monitors state of charge (SOC), rate of charge/discharge, state of health (SOH), voltage and temperature. The BMS is capable of disconnecting individual battery racks when faults are detected. BMS data is communicated via a programmable logic controller (PLC) and site supervisory control and data acquisition (SCADA) system to an off-site Remote Operations Control Center (ROCC).

3.2.2 Deflagration Protection System

The CEN enclosure is equipped with six roof mounted deflagration panels to provide pressure relief from overpressure events related to the ignition of flammable gases released during lithium-ion thermal runaway. The deflagration protection system has been designed in accordance with the 2023 edition of NFPA 68.

3.2.3 Smoke Detection

A smoke detection system is provided in the enclosure. A photoelectric smoke detector is provided at the roof level of the enclosure above each battery rack. Enclosure smoke detectors are monitored by the enclosure FACP. Alarm signals are communicated to the ROCC via the site SCADA system as well as communicated directly to the site FACP.

3.2.4 Gas Detection

The enclosure is provided with carbon monoxide and lower explosive limit (LEL) flammable gas detection. LEL gas detection is accomplished utilizing catalytic bead detectors which are sensitive to both hydrogen and hydrocarbon gases. Alarm signals are communicated to the ROCC via the site SCADA system as well as communicated directly to the site FACP.

3.2.5 Facility Occupant Notification

A combination horn/strobe is located on the exterior of each CEN enclosure for notifying nearby facility occupants of a hazardous condition within the enclosure. Activation of the notification device occurs upon detection of a low gas level, activation of a single smoke detector or discharge of the thermal runaway propagation suppression system.

3.2.6 Thermal Runaway Propagation Suppression System

A direct injection clean agent system is provided to limit propagation of a thermal runaway event. The system utilizes Novec 1230 (FK 5-1-12) clean agent. The system includes a pressurized storage cylinder and piping network to discharge agent directly above each cell vent area. The system is intended to cool a thermal runaway event, extinguish flames generated by an exothermic reaction, and limit propagation to adjacent cells by keeping cell surfaces below critical onset temperatures. The direct injection system is configured to be released by the FACP upon activation of two or more smoke detectors or activation of the manual pull releasing station located on the exterior of the enclosure. The effectiveness of the direct injection system was evaluated as a part of the installation level UL9540a test discussed in Section 4.0.

3.2.7 Electrical Fault Protection

Each module is equipped with a fusible link. Fuses are present on both the positive and negative terminals of each battery rack. Additionally, fuses are provided for each enclosure DC connection.

3.2.8 Emergency Stop

Final details to include details of how e-stop will be accomplished will be provided in final HMA report.

3.2.9 Site Specific Protections

The following features related to the project site provide additional protection:

3.2.9.1 Facility Layout

As shown in **Figure 5** below, the CEN enclosures are grouped in side-by-side pairs with 3.5 feet of space between each enclosure. Each pair is then spaced 29.67 feet from the next pair in groups totaling 5 pairs (10 CEN enclosures) with the exception of the top right group which includes only 4 pairs (8 CEN enclosures). The site consists of 4 total groups of enclosures separated by a minimum of 48 feet of space between them. If a fire evolves to the point it spreads beyond an enclosure, it is highly likely the pair will become involved. It is recommended that defensive firefighting be provided to mitigate further spread to adjacent pairs of enclosures. The additional separation between the pairs and the groups of enclosures helps to mitigate the potential for fire to spread throughout the site.

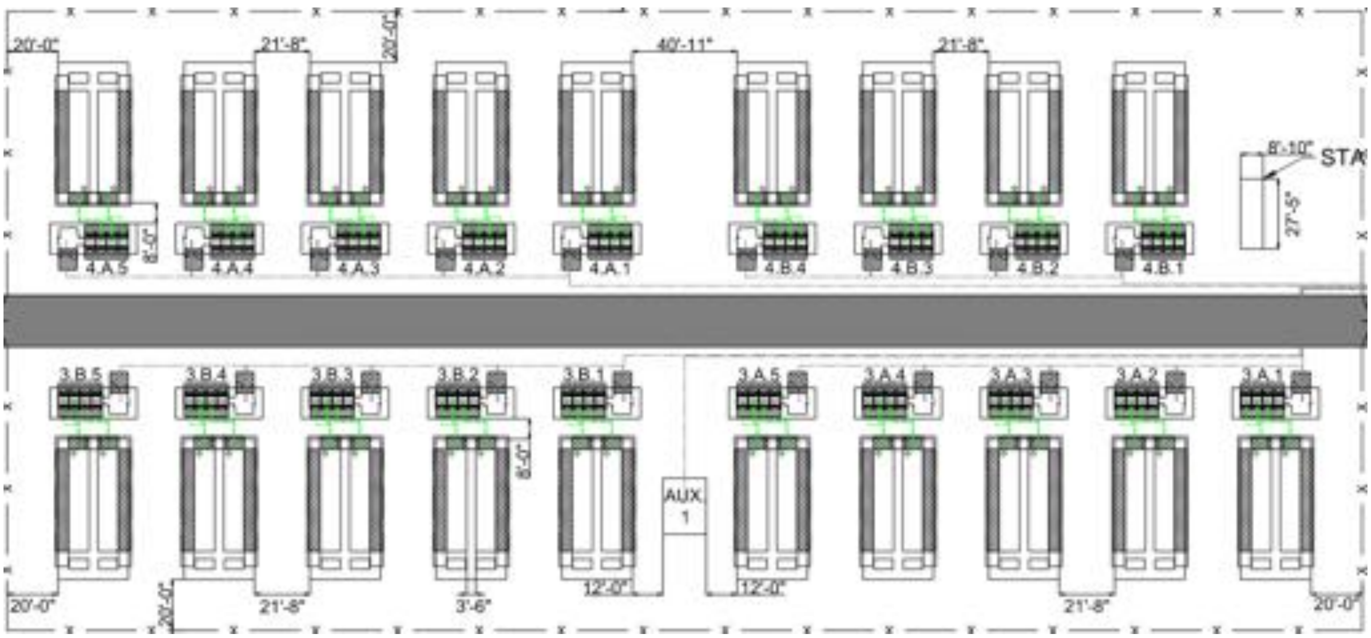

Figure 5 - E5N Enclosure Spacing

3.2.9.2 Vegetation Control

There will be a minimum 10-foot clearance between each side of the outdoor BESS units and combustible vegetation and other combustible growth as required by NFPA 855 section 9.5.2.2.

In accordance with 2021 IWUIC and Sante Fe County Ordinance 2023-06, a defensible space of 30 feet is required around the BESS enclosure structures given a moderate hazard classification as determined using the Santa Fe County Community Wildfire Protection Plan map. This may require modifications to the surrounding fuels such as vegetation to maintain the space in accordance with the requirements of IWUI Section 603. This will limit the potential for wildfires from surrounding areas to affect the BESS enclosures and vice versa. Additional defensible space can be provided around the BESS yard for additional protection beyond the code requirements.

3.2.9.3 Fire Water

The water supply at the Rancho Viejo site will be provided by a NFPA 1142 code compliant ground level water storage tank. The water tank will be provided with a water level gauge. The tank will be located west of the BESS field as shown in Figure 2. The water storage tank will be provided with a fire hose connection for fire department use; however, the site will not have any fire hydrants on the public water system. The water tank will have a 29,093-gallon nominal capacity.

The water supply is intended to provide fire flow to protect the energy storage system from incidental fire exposure from a non-energy storage system source or for defensive cooling of nearby equipment from an energy storage system related fire event. See below for three different fire scenarios analyzed to determine the appropriate water tank size to provide an adequate supply for emergency responders.

<u>Fire Scenario #1 – Power Conversion System (PCS) Fire Incident</u>
In this scenario, it is proposed that a fire is developing from a single PCS. It is assumed a PCS fire will require the same water supply as a transformer fire. FM Global DS 5-4, section 2.3.2.3 suggests a 1-hour hose stream flowing at 250 gpm for transformers holding FM approved liquids or up to 1,000 gallons of mineral oil. See below for the recommended fire water storage required for a PCS fire.

250 gpm x 60 minutes = 15,000 gallons of fire water

<u>Fire Scenario #2 – Exposure Fire Incident</u>
In an exposure fire incident, it is expected that a fire is emanating from a car or non-PCS equipment. In this scenario, two (2) handlines flowing at 200 gpm for 1-hour will have the capability to suppress a large exposure fire. See below for the recommended fire water storage required for an exposure fire:

200 gpm x 2 handlines x 60 minutes = 24,000 gallons of fire water

<u>Fire Scenario #3 – BESS Fire Incident</u>
In this scenario, it is proposed a fire originates from an BESS enclosure. The water volumes calculated above could assist emergency responders in intermittently cooling nearby exposures, control smoke, or extinguish small vegetation fires. For example, 24,000 gallons of fire water could intermittently (50% of the time) provide one (1) handline flowing at 200 gpm for 4-hours to cool nearby exposures. Alternately, if a fog nozzle is utilized, 24,000 gallons of fire water could provide two (2) handlines flowing 100 gpm intermittently (50% of the time) for a duration of 4-hours.

3.2.9.4 Site-Wide Fire Alarm System

While each individual CEN enclosure is installed with a FACP to monitor the local conditions and activate the internal suppression system, the site will also be provided with a site-wide fire alarm system and FACP capable of monitoring and reporting signals from each enclosure. The site-wide fire alarm system will be designed in accordance with NFPA 72 and will be capable of notifying the fire department during a fire event at an enclosure so that a response can be initiated. The fire alarm system will also be capable of notifying occupants within the BESS yard to alert them of a potential hazard.

3.2.9.5 Fire Department Response

The fire department will be automatically notified of an event at the project site via the FACP to assist in reducing the overall response time.

4.0 FIRE TESTING REVIEW

Full-scale fire testing provides a basis for the evaluation of thermal runaway fire propagation and the effectiveness of the fire protection strategy in mitigating potential harmful conditions arising from a thermal runaway event.

4.1 UL9540A TESTING

The CEN BESS system has been subject to testing utilizing the methods of UL 9540A at the cell, module, unit and installation levels. The UL 9540A test results are summarized below. Refer to the UL 9540A Cell, Module and Unit level test reports for detailed information. Full UL 9540A test reports are provided for review in Appendix F.

- **Cell Level Testing** – Cell level testing indicates that 423 L of gas may be released per cell when thermal runaway occurs. Testing indicates that the gas is primarily composed of hydrogen (32.7%), carbon monoxide (40.9%), methane (15.43%) and carbon dioxide (9.2%) with a LFL of 8.04% at ambient temperature. Refer to the *UL 9540A Cell Level Report* for detailed gas composition data. The average cell surface temperature at thermal runaway was 178°C. The cell vent gas fundamental burning velocity, S_u, was determined to be 88.40 cm/s with a maximum pressure, P_{max}, of 105.3 psig.

- **Module Level Testing** – Module level testing demonstrated that thermal runaway initiation of a single cell is capable of propagation throughout a majority of the cells within the module. The testing resulted in flaming combustion, flying debris, explosive discharge of gas and sparks or electrical arcs. A peak heat release rate (HRR) of 3935 kW was achieved during testing.

- **Unit Level Testing** – Unit level testing did not result in propagation of a thermal runaway event from the failure of a single cell. External flaming combustion was observed with a peak HRR of 426.1 kW. Release of flammable gas with an associated explosion was not observed. The maximum enclosure wall surface temperature observed was 169°C.

- **Installation Level Testing** – The installation level test is intended to collect information regarding the performance of the ESS's fire protection features. The installation level test included the operation of the direct injection clean agent cooling system. The installation level test did not result in propagation of a thermal runaway event from the failure of a single cell. No flaming or flying debris was observed outside of the enclosure. The maximum enclosure wall surface temperature observed was 670°C.

4.2 BESPOKE FIRE AND DEFLAGRATION TESTING

Bespoke Fire and Deflagration testing was conducted for this project. Test results are being processed and updates will be provided in the final version of the HMA report. The results will be evaluated and compared to local ambient conditions.

5.0 FIRE SAFETY ANALYSIS

This fire safety analysis is intended to provide a record of the decision-making process in determining the fire prevention, fire protection and explosion prevention measures for the identified hazards associated with the CEN BESS enclosure.

5.1 ANALYSIS METHODOLOGY

This analysis implements a bowtie methodology to holistically evaluate the CEN BESS enclosure against the analysis acceptance criteria identified in Table 2. The bowtie hazard assessment model developed in this analysis is described in ISO IEC 31010 Section B.21 and NFPA 855 Section G.4.

Bow tie modeling is a common hazard mitigation analysis tool used in the maritime, oil and gas, and utility industries. The strength of the bowtie approach comes from its visual nature, which evaluates the chronological pathways leading from threats to critical hazard events to consequences with the associated mitigative and preventative barriers in place to reduce or eliminate the said consequences. In this analysis, many of these threats parallel the hazards addressed by the fire code, such as unexpected thermal runaway.

As all threats and consequences tie into a single hazard event, the shape of the model resembles a bow tie. The length of the pathway on either side is dependent on the number of barriers that exist to prevent that threat from reaching the hazard event or the hazard event from devolving into the full consequence.

When assessed, the strength of each barrier is assessed in a qualitative manner. Barrier strength may vary depending upon the nature and stage of failure being assessed.

Refer to Appendix B for a full general description of the Bowtie methodology.

5.2 BOW TIE MODEL DEVELOPMENT

The bow tie model described in this section was used to evaluate the failure modes found in Table 1 against the noted analysis acceptance criteria found in Table 2.

5.2.1 Hazard and Top Event

The primary hazard of concern in this analysis is the considerable amount of energy contained with the BESS enclosure.

The top event is the moment when control over the hazard or its containment is lost. The central hazard event used in this analysis is defined as a single cell failure which begins to propagate through the system. This propagation may occur as the initiation of thermal runaway in adjacent cells or damage to adjacent equipment inside or outside the enclosure, or harm to personnel.

5.2.2 Threats and Preventative Barriers

The threats are arranged into four separate categories (primarily for presentation purposes), these include, threats resulting from thermal runaway or mechanical failure events, control and prevention system failure events, external impact failure events and electrical failures.

Table 5 and Table 6, below provides a brief summary of the threats and associated preventative barriers considered in this analysis. See Appendix C for a detailed review of each threat and preventative barrier. The resulting bow tie diagrams can be found in Appendix E. An assessment of the general strength of each individual barrier is also provided. While a general assessment is provided, the criticality and effectiveness of the barriers may vary based on the associated threat pathway.

Table 5: Threat Summary		
Threat	**Threat Description**	**Threat Category**
Single-Cell Thermal Runaway	A single cell has entered thermal runaway resulting in flames and combustion or production of flammable gases.	Thermal Runaway & Mechanical Failure
Multi-Cell Thermal Runaway	Multiple cells have entered thermal runaway.	Thermal Runaway & Mechanical Failure
Internal Defect / Failure (No Thermal Runaway)	A cell has failed as a result of an internal defect, creating a short circuit, open circuit, or other electrical condition or off-gas but not entering thermal runaway.	Thermal Runaway & Mechanical Failure
Hazardous Temperature Condition (Cell)	High temperature at the cell level during normal operations without thermal runaway.	Thermal Runaway & Mechanical Failure
Hazardous Temperature Condition (Module)	High temperature in the module during normal operation without failure / thermal runaway.	Thermal Runaway & Mechanical Failure
Hazardous Temperature Condition (Enclosure)	High temperature in the room or enclosure during normal operations	Thermal Runaway & Mechanical Failure
Electrical Hotspot / Loose Connection	Loose connections in the system may increase resistance and cause hotspots. Hotspots may form in other ways for unknown reasons. These hotspots will then conduct via bus bars or mechanical contact into cells.	Thermal Runaway & Mechanical Failure
Impact	Something has struck, sharply or as blunt force, the battery system, causing mechanical damage or deformation.	External Impact Failures
Water Damage (Flooding)	The system is flooded with water as a result of cooling system failure.	External Impact Failures
Water Damage (Condensation)	The system is subject to uncontrolled condensation of water via dehumidifier failure, internal condensation of moisture, or from natural reasons.	External Impact Failures
External Fire Impingement	An external fire that is impinging on the system from outside the containment.	External Impact Failures
Dust / Dirt / Particulate Accumulation	Accumulation of dust, dirt, or particulate that results in an adverse condition inside the system.	External Impact Failures
Human Factors	An adverse condition caused by the result of human interaction, error, or imperfection.	External Impact Failures
Module Cooling or HVAC System Failure	Mechanical or electrical failure of the module cooling or enclosure HVAC system resulting in high temperatures throughout system.	Control & Prevention System Failure
Sensor Failure	A sensor inside the system fails, resulting in incorrect reporting of system properties.	Control & Prevention System Failure
BMS Failure	Cell / module level monitoring and control fails, resulting in inability to shut down, report adverse conditions, properly monitor, balance, or protect the system resulting in an adverse condition.	Control & Prevention System Failure
Enclosure PLC Failure	Failure of the enclosure PLC controller resulting in adverse condition to the system or inability to detect or protect against adverse conditions under its purview.	Control & Prevention System Failure

Table 5: Threat Summary		
Threat	**Threat Description**	**Threat Category**
Site Control / Balance of Plant / PLC Failure	Failure of the master site controller or other balance of system controller resulting in adverse condition to the system or inability to detect or protect against adverse conditions under their purview.	Control & Prevention System Failure
Shutdown / Isolation Failure	Failure of the system to shut down or isolate itself when an adverse condition is detected.	Control & Prevention System Failure
Hazardous Voltage Condition	This could include high line voltages, floating ground issues, or other high voltage issues at the cell, module, or rack level.	Electrical Failure
Ground Fault / Isolation Fault	This could include localized shorting of cells, shorting between modules, shorting of entire racks or systems and ground fault shorting.	Electrical Failure

Table 6: Preventative Barrier Summary	
Barrier	**Preventative Barrier Description**
Passive Module Protections	Module fuses which may open the circuit in the case of failure as well as the general resilience of design to withstand adverse electrical conditions.
Liquid Cooling System	The liquid cooling system is an active cell protection which may prevent thermal runaway propagation.
Enclosure Dehumidification System	The enclosure's dehumidification system acts to prevent the buildup of condensation that may pose a short circuit hazard.
Direct Injection Clean Agent System	The direct injection clean agent system is an active cell protection which may prevent thermal runaway propagation.
Cell Thermal Abuse Tolerance	Ability of the cells to withstand thermal abuse without going into failure themselves.
Cell Quality Control	Overall quality of the cell such that internal defects are minimized, and cells maintain rigidity and shape during operations. Also includes tight tolerances with respect to degradation and new capacity.
BMS Control	Includes monitoring and shutdown/isolation capabilities of the affected BMS / module or system.
Temperature Monitoring and Alarms	Thermal monitoring within the enclosure.
System Shutdown / Disconnect	Ability of system to actively shut itself down or disconnect itself. This is the aggregate of the BMS ability as well as physical disconnects and the Balance of System controller's ability to shut down.
Preventative Maintenance and Commissioning	Proper maintenance and monitoring of the system in conjunction with adequate commissioning and site acceptance testing to reduce likelihood of loose connections or other transportation- or construction-related defects.
Passive Circuit Protection and Design	Breakers and fuses which may open the circuit in the case of failure as well as general resilience of design to withstand adverse electrical conditions.
Cell Electrical Abuse Tolerance	Ability of the cell to withstand electrical abuse such as overcharge, over discharge, high currents, or other adverse electrical abuse.
Redundant Failure Detection / System Intelligence	The ability of the system to determine a sensor has failed, to operate safely without that sensor to shut down, or operate safely indefinitely without sensor. This may include Checksums, additional sensors, or the ability to pull data from other sensors.

Table 6: Preventative Barrier Summary	
Barrier	**Preventative Barrier Description**
Human Factors / Process Control	Quality control or other processes put in place to prevent mishandling of systems that may result in adverse or hazardous conditions or mishandling.
Enclosure / Structural Resiliency	Resiliency of the system and enclosure of the system to withstand impacts or strikes.
Module Resiliency	Resiliency of the individual modules to withstand impacts, shocks, or other mechanical abuse.
Cell Physical Abuse Tolerance	Ability of the cell to withstand thermal, physical, or mechanical abuse.
Humidity Monitoring	Monitoring within the enclosure which may detect high humidity, water condensation or water leakage.
System Maintenance	Proper preventative maintenance to minimize the impact of adverse, long term or slow acting environmental effects resulting in degradation.
SME Training	Proper training procedures, availability of subject matter expertise and system competence, and clear jurisdictional hierarchy for managing situations.
Voltage Monitoring	Overall effectiveness of the voltage monitoring scheme of the system. Includes resilience to errors, error checking, and other measurement intelligence.
Insulation Monitoring	Continual, or active, monitoring of insulation integrity, ground versus float voltage, and other practices to prevent insulation or isolation degradation.

5.2.3 Consequences and Mitigative Barriers

Table 7 and Table 8, below provides a brief summary of the consequences and associated mitigative barriers considered in this analysis. See Appendix D for a detailed review of each consequence and mitigative barrier. The resulting bow tie diagrams can be found in Appendix E. An assessment of the general strength of each individual barrier is also provided. While a general assessment is provided, the criticality and effectiveness of the barriers may vary based on the associated consequence pathway.

Table 7: Consequence Summary	
Consequence	**Consequence Description**
Cell / Module Combustion	A battery cell or module has failed and is now producing flame or combusting.
Multi-Module / Rack Fire	Multiple modules have begun producing flame or combusting.
Fire Spread Beyond Enclosure Fire Partition	A fire within the system has spread from one side of the enclosure fire separation to the modules/rack and equipment on the opposite side within the same enclosure.
Fire Spread Beyond Enclosure	A fire within the system has spread beyond the enclosure to adjacent BESS enclosures or other structures.
Cell Off-Gassing / Explosions	A cell or multiple cells have failed or entered thermal runaway and is now producing off-gas.
Accumulation of Off-Gasses / Delayed Explosions	A cell or multiple cell failure which may or may not have propagated has resulted in the accumulation of potentially explosive off-gas within the enclosure.
Balance of System Fire	A fire that either is initiated in or results in the involvement of a balance of system fire such as wire insulation, electrical components, or plastic inside the system.
Environmental / HAZMAT Issues	A large-scale system fire has resulted in an environmental or hazardous material incident which requires hazardous material response.

Table 8: Mitigative Barrier Summary	
Barrier	**Mitigative Barrier Description**
Enclosure Smoke Detection	Activation of the enclosure's smoke detection system and communication via the FACP. System activation provides both situational awareness to facility operators, personnel in the vicinity of the enclosure, and first responders as well as activation of the enclosure's direct injection clean agent system.
Enclosure Gas Detection System	Activation of the enclosure's gas detection system and communication of alarm signal to the SCADA system. System activation provides situational awareness to facility operators, personnel in the vicinity of the enclosure and first responders.
Occupant Notification	Activation of the alarm notification device on the exterior of the enclosure and activation of the facility's site wide alarm system if provided.
BMS Data Availability	Includes BMS measurements available to first responders, Facility Operations Center or other SMEs. Effectiveness based on what is detected and how well, how this information is being conveyed, and robustness of sensors in case of failure.
Direct Injection Clean Agent System	Activation of the direct injection clean agent system may limit or reduce the rate of a propagating thermal runaway event.
Deflagration Protection	Activation of the enclosures deflagration venting system.
Thermal Isolation (Enclosure Insulation)	Passive thermal propagation protection provided by insulation installed on the boundaries of the enclosure.
Thermal Isolation (Enclosure Fire Separation)	Passive thermal propagation protection provided the enclosure's fire separation.
Thermal Isolation (Module / Rack Separation)	Passive thermal propagation protection provided by physical separation between modules within a rack and physical separation between racks within the enclosure.
Facility Design and Siting	Placement of the facility such that adverse environmental effects such as flooding, vehicle impact, and fire impingement are mitigated or avoided. The strength of this barrier is dependent upon the site-specific aspects of the facility layout.
Emergency Response Plan / First Responders	System operator plan to handle any and all emergency events. A site-specific emergency response plan should be developed. Effectiveness based on level of the subject matter expert (SME) / first responder training, knowledge of the specific BESS undergoing failure, coordination with fire department, etc.
Fire Service Response	Fire department response including active firefighting suppression. Effectiveness based on level of department knowledge and training to effectively respond both offensively and defensively during an BESS incident.

5.3 FAULT CONDITION ANALYSIS

The fault condition analysis below uses the four bow tie diagrams shown below as Figure 6 through Figure 9 for evaluation of the failure modes against the acceptance criteria identified in Table 2. See Appendix E for enlarged versions of the bow tie diagrams.

Figure 6 – Thermal Runaway and Mechanical Failure Bow Tie Diagram

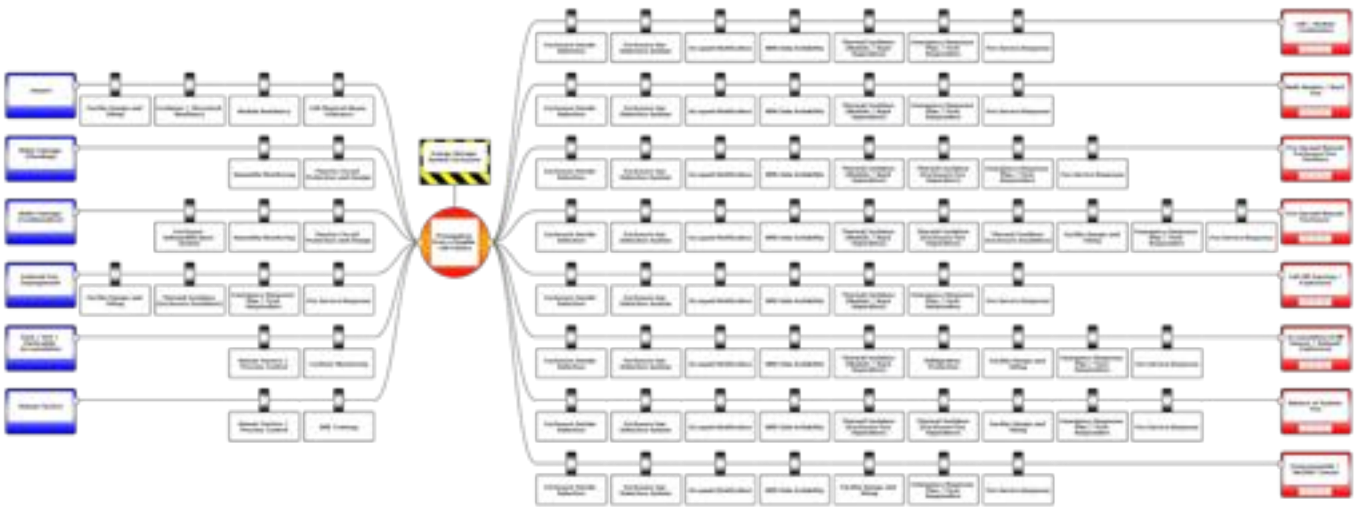

Figure 7 – External Impact Failures Bow Tie Diagram

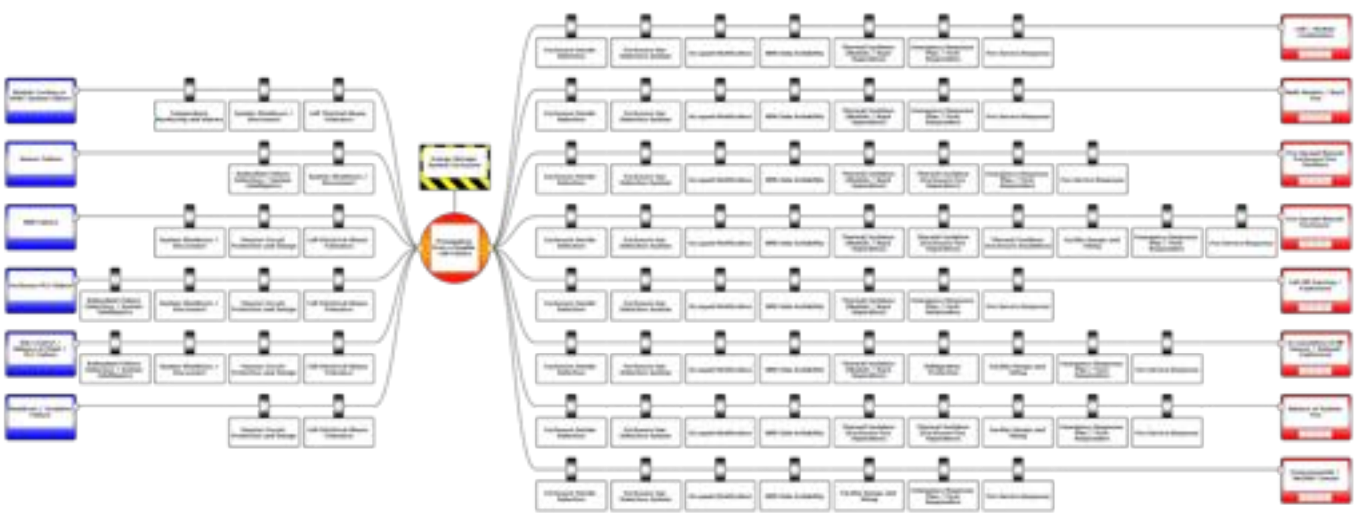

Figure 8 – Control and Prevention System Failure Bow Tie Diagram

Figure 9 – Electrical Failure Bow Tie Diagram

5.3.3 Failure Mode 1: Single BESS unit Thermal Runaway or Mechanical Failure

Failure Mode 1 considers a thermal runaway or mechanical failure in a single BESS unit. The analysis for this failure mode primarily uses the thermal runaway & mechanical failure (see Figure 6), and the external impact threat pathway (see Figure 7) bow tie diagrams.

The threats identified in Figure 6 and Figure 7 can lead to a thermal runaway event in a single or group of cells due to a direct cell failure or indirectly from other root causes. Specific threats include conditions arising from within the enclosure such as internal cell defects and high heat conditions as well as conditions arising externally such as impacts from external fire events and flooding. Other conditions that may lead to a propagating cell failure event via electrical, control system and prevention system failures are examined in subsequent report sections.

Several active and passive barriers act to prevent a propagating cell failure scenario from developing from these threats. Key preventative barriers in the CEN enclosure product design include, passive module protections, cell thermal abuse tolerance, liquid cooling system, direct injection clean agent system, BMS control system, passive circuit protection, enclosure monitoring system and the enclosure insulation. Other key preventative barriers that may be present or in varying strengths depending upon the final site installation include, system shut down capability, facility design and siting, emergency planning and fire service response.

Once a propagating failure event has occurred, the smoke detection, gas detection and BMS data availability mitigation barriers act to provide situational awareness to facility operators and emergency responders. The strength of these barriers will be dependent upon site installation conditions. The enclosure, fire separation and module thermal isolation barriers act to limit the propagation of the escalating event. The deflagration protection barrier mitigates the possible effects of explosions. The facility siting, emergency response/planning and fire service response barriers are anticipated to provide additional barriers to mitigate an incident depending upon final site conditions.

During a thermal runaway event, several of the provided safety barriers would be expected to slow the growth of a failure event (i.e. thermal isolation, direct injection clean agent system, etc.). The slower rate of propagation with these barriers in effect acts to increase the effectiveness of the smoke and gas detection systems by providing an increased amount of time for event detection prior to the development of untenable conditions adjacent to the enclosure. With the situational awareness provided by activation of the occupant notification appliances located on the exterior of the enclosure, sufficient time is anticipated to be provided to allow for evacuation of facility occupants to a safe location. The final site installation and operation conditions may act to further multiply the effectiveness of this barrier, such as occupant evacuation training and a site wide fire/emergency notification system.

The accumulation of cell off-gas from a thermal runaway event presents an explosion hazard. This hazard is specifically evaluated in the bow tie model as a possible consequence. The provided deflagration venting system provides a strong barrier to mitigate the effects of deflagration events resulting from a thermal runaway event of up to three cells. Given the previously mentioned safety barriers which act to reduce the rate of propagation of an escalating event, the proposed deflagration system is deemed to be adequate. The gas detection system has the capability to provide situational awareness of internal conditions to emergency and fire service responders.

5.3.2 Failure Mode 2: Failure of a Required Protection System not Covered by Product Listing FMEA

This failure mode considers the failure of an energy storage management system or protection system that is not covered by the product listing failure modes and effects analysis (FMEA). The analysis for Failure Mode 2 uses the control and prevention system failure threat pathway bow tie diagram (see Figure 8).

Specific threats analyzed for this failure mode included cooling system failure, sensor failure, BMS failure, site control / PLC failure and shutdown isolation failure. While none of these threats lead directly to the failure of a cell, they can serve as precursor events to cell failure.

The safety barriers preventing the threats considered in this failure mode from escalating to a propagating cell failure event primarily include cell electrical and thermal abuse tolerance, passive circuit protection and design, and system shutdown / disconnect capability. The effectiveness of the system shutdown / disconnect capability may be subject to site conditions.

The mitigative barriers available once a propagating event has begun are typical to those discussed in the Failure Mode 1 section above.

The assessment of the identified safety barriers to limit the possible consequences to what is specified in the analysis acceptance criteria is typical to the discussion found in the Failure Mode 1 section above.

5.3.3 Failure Mode 3: Failure of a Required Protection System

Failure Mode 3 considers the failure of a required protection system. The analysis for this failure mode primarily uses the thermal runaway & mechanical failure (see Figure 6), and the external impact threat pathway (see Figure 7) bow tie diagrams.

For this failure mode, the consequences are evaluated with required protection systems assumed to have failed and be out of service. The model was separately evaluated assuming failures of the enclosure smoke detection system, enclosure gas detection system, deflagration protection system and direct injection clean agent system. Simultaneous multiple system failures are not considered. Failure of any of the above listed system is not anticipated to immediately create a hazardous condition, rather, failure of a required protection system will reduce the ability to prevent or mitigate hazardous conditions developing from a fire or thermal runaway event.

A failure of the smoke detection system would be expected to lead to a failure of the direct injection clean agent system and in a possible reduction in the overall situational awareness during an emergency. In this case, the gas detection system and BMS data safety barriers act to provide a degree of continued situational awareness. Activation of the gas detection system is expected to occur during a fire or thermal runaway incident and provide activation of the occupant notification system even if a failure occurs in the smoke detection system. The direct injection clean agent system may be released using the manual pull station on the outside of the enclosure if the smoke detection system is not functioning. The strength of the gas detection and direct injection clean agent system barrier is conditional based on the quality and use of the emergency plan, and the quality of communication between the ROCC and on-site personnel. Other safety barriers such as thermal abuse tolerance and thermal isolation are expected to continue at their previous performance level.

Failure of the gas detection system is not anticipated to result in a significant reduction in safety as this system primarily provides situational awareness. The deflagration prevention system, which uses a passive deflagration vent design, is expected to continue providing a strong safety barrier against explosion type hazard when gas detection system failure occurs.

The deflagration prevention system uses a NFPA 68 compliant passive vent design that does not rely upon electrical or mechanical systems to maintain safety. The passive design is expected to have greater availability as compared to active system designs which use ventilation or other methodologies to maintain safety. If the deflagration prevention system fails, the gas detection system would be expected to provide a degree of situational awareness regarding an escalating flammable gas event within the enclosure.

The direct injection clean agent system is treated as a preventative barrier within this analysis. All threat pathways considered in this failure mode feature multiple additional preventative and mitigative barriers.

The CEN enclosure is evaluated to include a sufficient quantity of safety barriers, such that the failure of any one of the required protection systems is not expected to result in a situation where the rate of event propagation will prevent the evacuation of facility occupants to a safe location.

This can also include the failure of site-wide fire alarm monitoring and reporting, however a system installed in accordance with NFPA 72 helps to mitigate the potential for a failure in which the fire department is not made aware.

5.3.4 Failure Mode 4: Primary Electric Supply Voltage Surges

The analysis for Failure Mode 4 uses the Hazardous Voltage Condition pathway on the electrical system failure threat bow tie diagram (see Figure 9).

The primary safety barriers expected to prevent a propagating cell failure are voltage monitoring and BMS control. The system shutdown and passive circuit protection barriers are expected to also provide preventative barriers. The effectiveness of the system shutdown / disconnect capability may be subject to site conditions.

The mitigative barriers available once a propagating event has begun are typical to those discussed in the Failure Mode 1 section above.

The assessment of the identified safety barriers to limit the possible consequences to what is specified in the analysis acceptance criteria is typical to the discussion found in the Failure Mode 1 section above.

5.3.5 Failure Mode 5: Load Side Short Circuits

The analysis for Failure Mode 5 uses the Ground Fault / Isolation Fault pathway on the electrical system failure threat bow tie diagram (see Figure 9).

The primary safety barriers expected to prevent a propagating cell failure are BMS control and passive circuit protection barriers. Insulation monitoring can also serve to prevent this type of failure.

The mitigative barriers available once a propagating event has begun are typical to those discussed in the Failure Mode 1 section above.

The assessment of the identified safety barriers to limit the possible consequences to what is specified in the analysis acceptance criteria is typical to the discussion found in the Failure Mode 1 section above.

6.0 ANALYSIS APPROVAL

The acceptance criteria applied in this analysis aligns to the HMA approval criteria listed in the 2023 edition of NFPA 855 and the 2021 edition of the IFC. Conformance with the specified acceptance criteria is demonstrated in Table 9 below.

Table 9: Compliance with Analysis Acceptance Criteria

Acceptance Criteria	Acceptance Criteria and Demonstration of Compliance	
1	Requirement:	Fires and products of combustion will not prevent occupants from evacuating to a safe location
	Conformance:	The CEN enclosure features a sufficient quantity of safety barriers to limit the rate of propagation of an escalating fire or thermal runaway event and provide adequate situational awareness to facility occupants to permit evacuation to a safe location.
2	Requirement:	Deflagration hazards will be addressed by an explosion control or other system
	Conformance:	This analysis has identified that a propagating cell failure event poses a deflagration hazard. The CEN enclosure will be equipped with a NFPA 68 compliant deflagration venting system to release the combustion gases and pressure resulting from a deflagration within the enclosure so that structural and mechanical damage is minimized.

7.0 ANALYSIS ASSUMPTIONS AND LIMITATIONS

The analysis presented in this analysis is limited by the following key assumptions:

- **Unknown Failure Modes** – While large-scale fire testing and commitment of considerable resources to the study of energy storage safety issues has drastically improved the industry’s understanding of failure modes, threats, consequences and general safety, many failure modes and corresponding responses remain uncharacterized. Unknown failures may also potentially arise not otherwise considered in this analysis. The conclusions of this analysis should be re-evaluated as such failure modes become known to the industry.
- **Outside Event effecting more than one unit** – Several of the identified failure modes may affect multiple enclosures simultaneously, examples include flooding, external fires and voltage surges. The effectiveness of some safety barriers may be degraded when multiple events are occurring simultaneously and thus may not perform at the same strength as compared to when preventing or mitigating a single event. While this analysis does not directly consider events affecting more than a single unit at a time, it can be assumed that the risk of event propagation will be increased as more enclosures are involved.

- **Hazards during Construction, Shipping and Storage** – This analysis does not evaluate the hazards associated with the construction, off-site storage and shipping of the BESS enclosures. Other hazards may exist during these phases that are not present during operation of the enclosure.
- **Continued Maintenance** – All BESS systems are assumed to be inspected, tested and maintained in accordance with the original equipment manufacturer's instructions and as required by regulatory requirements. A lack of inspection, testing and maintenance of BESS subsystems can be expected to have a detrimental effect on the strength of the provided safety barriers.
- **Installed per code** – All life safety, fire protection and explosion systems are assumed to be installed and maintained in accordance with the applicable installation standards as required by the IFC. This report does not specifically evaluate the compliance of any protection systems to applicable installation standards.

8.0 REFERENCED DOCUMENTATION

In addition to the code documents listed in this report, other documents reviewed as part of this report were all provided by the project team. These documents include:

- *AES CEN Project BESS Container General and Internal Arrangement* drawings, CEN Solutions, Revision 0, Dated January 3, 2024
- *McFarland B – BESS Signals Logic Specific Project Procedure*, CEN Solutions, Revision 3, Dated October 16, 2023
- *30% Electrical Documents for Rancho Viejo Solar Utility BESS*, PVInsight Inc., Revision 3, Dated 07/02/2024
- *30% Civil Documents for Rancho Viejo Solar Utility BESS*, PVInsight Inc., Revision 3, Dated 07/02/2024
- *30% Structural Documents for Rancho Viejo Solar Utility BESS*, PVInsight Inc., Revision 2, Dated 03/04/2024
- *UL 9540A Report – Cell Level Report* (Project No. 4790746849), Dated July 7, 2023
- *UL 9540A Report – Module Level Report* (Project No. 4790351859), Dated July 10, 2023
- *UL 9540A Report – Unit Level Report* (Project No. 4790648531), Dated July 6, 2023
- *UL 9540A Report – Installation Level Report* (Project No. 4790648557), Dated July 7, 2023
- *Bespoke Fire Testing Reports to be added*

9.0 QUALIFICATIONS AND LIMITATIONS STATEMENT

The opinions and recommendations made in this report have been rendered using our professional judgment after our visual inspection and an evaluation of the information obtained from the documents provided to Coffman. The information contained within this report is specific to this project and should not be applied to any other facility or operation. We assume no liability for the work, opinions or reports of any other independent consulting firm engaged to do so. The analysis detailed in this report is based upon our engineering judgment using codes, standards, and research publicly available to-date relative to lithium-ion batteries. The recommendations in this report are advisory in nature. It is the sole responsibility of the client to implement the conclusions and recommendations contained herein.

APPENDIX A – NFPA 855 AND IFC HAZARDOUS MITIGATION ANALYSIS REQUIRMENTS

A1. INTRODUCTION

This Appendix compares the HMA failure mode and analysis approval requirements as found in the below listed codes to the failure modes and approval requirements selected for the analysis contained in this Fire Safety Technical Report.

- *International Fire Code* (IFC), 2021 edition
- NFPA 855, *Standard for the Installation of Energy Storage System*, 2023

A1.1. FAILURE MODES

The single mode failure modes considered in this analysis are described in Table 1. Table 2 below, relates the failure mode requirements as found in NFPA 855 and the IFC to the failure mode requirements applied to this analysis.

Table 1: Analysis Failure Modes	
Failure Mode	**Failure Mode Description**
1	A thermal runaway or mechanical failure in a single ESS unit.
2	Failure of an energy storage management system or protection system that is not covered by the product listing failure modes and effects analysis (FMEA).
3	Failure of a required protection system including, but not limited to, ventilation (HVAC), exhaust ventilation, smoke detection, fire detection, fire suppression, or gas detection.
4	Voltage surges on the primary electric supply.
5	Short circuits on the load side of the ESS.

Table 2: NFPA 855 and IFC Failure Mode Requirements		
Code or Standard	**Failure Mode Description**	**As Applied in This Analysis**
NFPA 855 (2023 edition) Section 4.4.2.1	(1) A thermal runaway or mechanical failure in a single ESS unit.	Addressed in this analysis as Failure Mode #**1** (See Table 1).
	(2) Failure of an energy storage management system or protection system that is not covered by the product listing failure modes and effects analysis (FMEA).	Addressed in this analysis as Failure Mode #**2** (See Table 1).
	(3) Failure of a required protection system including, but not limited to, ventilation (HVAC), exhaust ventilation, smoke detection, fire detection, fire suppression, or gas detection.	Addressed in this analysis as Failure Mode #**3** (See Table 1).
IFC (2021 Edition) Section 1207.1.4.1	(1) A thermal runaway condition in a single ESS rack, module or unit.	Addressed in this analysis as Failure Mode #**1** (See Table 1).
	(2) Failure of any battery (energy) management system	Addressed in this analysis as a component of Failure Mode #**2** (See Table 1).
	(3) Failure of any required ventilation or exhaust system	Addressed in this analysis as a component of Failure Mode #**3** (See Table 1).
	(4) Voltage surges on the primary electric supply	Addressed in this analysis as Failure Mode #**4** (See Table 1).

	(5) Short circuits on the load side of the ESS	Addressed in this analysis as Failure Mode #**5** (See Table 1).
	(6) Failure of the smoke detection, fire detection, fire suppression or gas detection system	Addressed in this analysis as a component of Failure Mode #**3** (See Table 1).
	(7) Required spill neutralization not being provided or failure of a required secondary containment system	Not Applicable – Secondary containment are not required for lithium-ion battery types.

A1.2. ACCEPTANCE CRITERIA

The acceptance criteria considered in this analysis are described in Table 3. Table 4 below, relates the approval criteria requirements as found in NFPA 855 and the IFC to the acceptance criteria applied to this analysis.

Table 3: Analysis Acceptance Criteria

Acceptance Criteria	Acceptance Criteria Description
1	Fires and products of combustion will not prevent occupants from evacuating to a safe location
2	Deflagration hazards will be addressed by an explosion control or other system

Table 4: NFPA 855 and IFC Approval Criteria Requirements

Code or Standard	Approval Criteria Requirements	As Applied in This Analysis
NFPA 855 (2023 edition) Section 4.4.3	(1) Fires will be contained within unoccupied ESS rooms for the minimum duration of the fire resistance rating specified in NFPA 855 Section 9.6.4	Not Applicable – The E5S enclosure does not constitute a room, nor is the E5S enclosure intended to be used indoors.
	(2) Fires and products of combustion will not prevent occupants from evacuating to a safe location	Addressed in this analysis as Acceptance Criteria #**1** (See Table 3).
	(3) Deflagration hazards will be addressed by an explosion control or other system	Addressed in this analysis as Acceptance Criteria #**2** (See Table 3).
IFC (2021 Edition) Section 1207.1.4.2	(1) Fires will be contained within unoccupied ESS rooms or areas for the minimum duration of the fire-resistance-rated separations identified in IFC Section 1207.7.4	Not Applicable – The E5S enclosure does not constitute a room, nor is the E5S enclosure intended to be used indoors.
	(2) Fires in occupied work centers will be detected in time to allow occupants within the room or area to safely evacuate	Not Applicable – The E5S enclosure is not intended to be used indoors.
	(3) Toxic and highly toxic gases released during fires will not reach concentrations in excess of the IDLH level in the building or adjacent means of egress routes during the time deemed necessary to evacuate occupants from any affected area	Addressed in this analysis as Acceptance Criteria #**1** (See Table 3).

	(4) Flammable gases released from ESS during charging, discharging and normal operation will not exceed 25 percent of their LFL	Not Applicable – Lithium-ion cells are hermetically sealed and do not vent under normal charging or discharging operating conditions. Flammable gases are not released during normal operations.
	(5) Flammable gases released from ESS during fire, overcharging and other abnormal conditions will be controlled through the use of ventilation of the gases, preventing accumulation, or by deflagration venting	Addressed in this analysis as Acceptance Criteria #2 (See Table 3).

APPENDIX B – BOW TIE METHODOLOGY

B1. INTRODUCTION

This Appendix provides a general description of the bow tie methodology as a hazard analysis tool.

The bow tie methodology is common is risk and hazard studies to identify the safety barriers that can be implemented to prevent a critical event from happening and/or to mitigate its effects after it has occurred [1]. In bow tie models, a fault tree and event tree are linked to a critical event that is related to an undesirable event. In this way, bow tie models represent the relationship that exists between hazards, threats, safety prevention barriers, safety mitigation barriers and consequences.

The strength of the bowtie approach comes from its visual nature. An example of a bow tie model is given below in

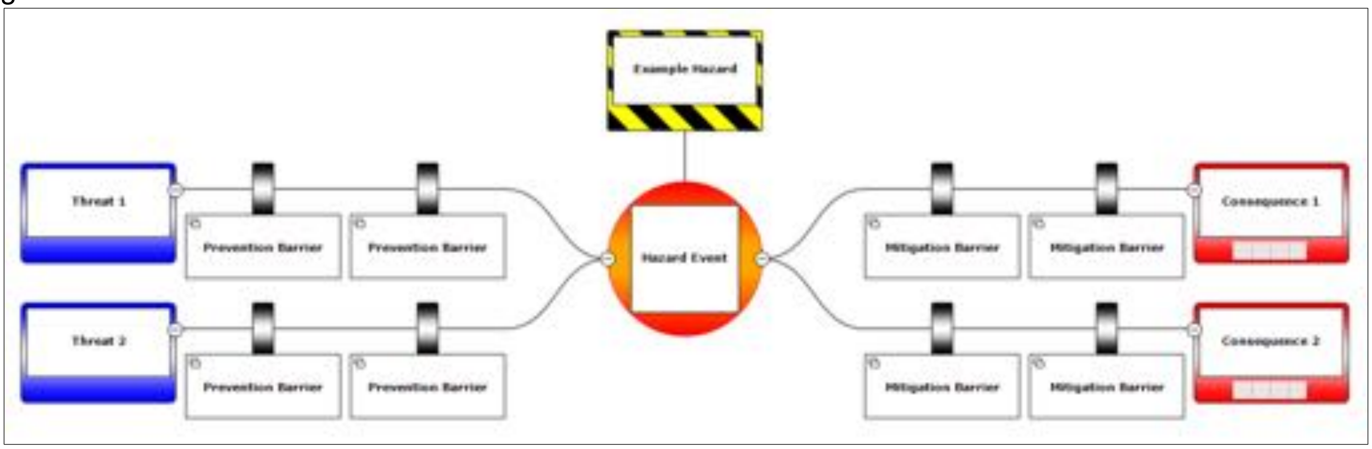

Figure **1**.

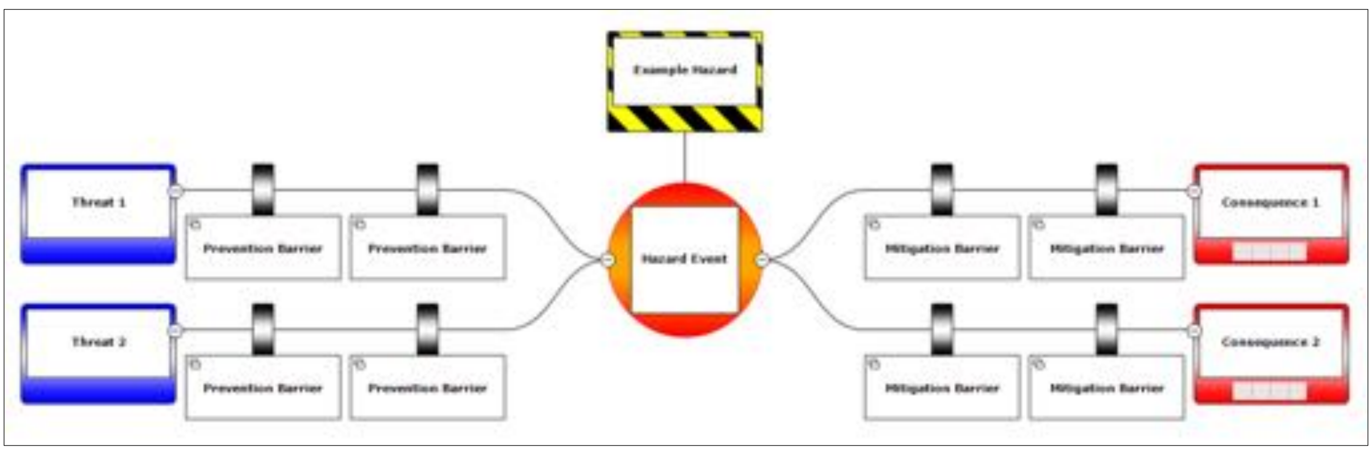

Figure 1 – Bow Tie Model Description

B2. BOW TIE ELEMENTS

Bow tie models contain the elements listed below:

- **Hazard** – The hazard is an operation, activity or material with the potential to cause harm. It is shown on bow tie model diagrams to provide clarity to the reader as to the source of risk. Hazards are part of normal business and are often necessary to run an operation.

- **Top Event** – The top event is the moment when control over the hazard or its containment is lost. While the top event may have occurred, there may still be time for barriers to act to stop or mitigate the consequences.
- **Threats** – Threats are the potential reasons for loss of control of the hazard leading to the top event. For each top event there are normally multiple threats located on the left side of the bow tie model diagram, each representing a single scenario that could directly and independently lead to the event.
- **Consequences** – Consequences are unwanted outcomes that could result from the top event and lead to damage or harm. Generally, these would be major accident events, but lesser consequences can be selected if the aim is to map the full range of important safety and environmental barriers. One top event may have multiple consequences, but normally only important consequences would be developed to show the mitigation of barriers, not trivial ones.
- **Barriers** – Barriers can be physical or non-physical measures to prevent or mitigate unwanted events. Active barriers can differ with respect to 'detect', 'decide' and 'act' components they contain and whether these components are performed by humans or executed by technology.
    - **Prevention Barriers** – A prevention barrier is a barrier that prevents the top event from occurring. A key test for a prevention barrier is that it must be capable of completely stopping the top event on its own. These barriers appear to the left of the top event on the bow tie model diagram.
    - **Mitigation Barriers** – Mitigation barriers are employed after the top event has occurred and act to prevent or reduce losses and regain control once it has been lost. These barriers appear to the right of the top event on the bow tie model diagram.

The bow tie element descriptions provided above, is based on information found in *Bow Ties in Risk Management* as developed by the Center for Chemical Process Safety [2].

B3. ADVANTAGES, DISADVANTAGES AND UNCERTAINTIES

All hazard analysis techniques are subject to certain advantages, disadvantages and uncertainties. These items are summarized below for the bow tie methodology. The summary provided below is based upon information found in *A Guide to Hazard Identification Methods* [3].

B3.1. ADVANTAGES

- **Hazard Communication** – Bow tie model diagrams communicate:
    - a clear picture of the possible consequences and the routes in which they arise
    - the necessary conditions and sequences of events for each to occur
    - the relative importance of each safety barrier and the consequence of failure
    - the points where additional safety barriers are needed
    - the conditions requiring further in-depth analysis
- **Facilitate hazard-event-consequences Understanding** – The analysis and its visual representation can help all concerned with the safety of a facility to recognize the sequence that could lead to catastrophic events and to appreciate maintaining preventative and mitigation barriers.
- **AHJ Communication** – Regulatory authorities can be assured that a full analysis has been carried out and that hazards are understood and satisfactorily controlled.

B3.2. DISADVANTAGES

- **Requires Detailed Process Understanding** – The analyst needs to be skilled in the use of bow ties, particularly in determining the degree of detail to be included and have a detailed understanding of the system under analysis.
- **Poor Data** – The value of a study will be limited if the available data is of poor quality and lacks robustness or relevance. Imprecise data leads to imprecise predictions.
- **Treat with Care** – All results must be treated with care.

B3.3. UNCERTAINTIES

- **Common Mode Failures** – It is essential that full allowance is made for common mode failures and it may be necessary to make an arbitrary allowance for the possibility of these events.

B4. APPENDIX B REFERENCES

[1] S. Mannan, Lees' Loss Prevention in the Process Industries, Waltham, MA: Elservier, 2012.

[2] Center for Chemical Process Safety of the American Institute of Chemical Engineers, Bow Ties in Risk Managment, Hoboken, NJ: John Wiley & Sons, Inc., 2018.

[3] F. Crawley, A Guide to Hazard Identification Methods, Cambridge, MA: Elsevier, Inc., 2020.

APPENDIX C – THREAT AND PREVENTATIVE BARRIER DESCRIPTIONS

Table 1: Detailed Threat Descriptions		
Threat	**Threat Description**	**Threat Category**
Single-Cell Thermal Runaway	*A single cell has entered thermal runaway resulting in flames and combustion or production of flammable gases.* This scenario may occur as a result of an internal cell defect or other cause. Single cell thermal runaway events may not be readily detectable if the event scenario does not propagate beyond the initial event. If no ignition source is present, the failure may result in the generation of hazardous and flammable gases that could lead to other hazards. If an ignition source is present, the byproducts may combust and result in fire. The UL 9540A module, unit and installation level test for the E5S ESS enclosure utilizes a single cell thermal runaway event as an initiating event.	Thermal Runaway & Mechanical Failure
Multi-Cell Thermal Runaway	*Multiple cells have entered thermal runaway.* Multicell thermal runaway is a credible failure mode that may result from the overcharge of a parallel cell group or the early results of a propagating cell failure. Multicell thermal runaway may prove manageable and containable in some cases.	Thermal Runaway & Mechanical Failure
Internal Defect / Failure (No Thermal Runaway)	*A cell has failed as a result of an internal defect, creating a short circuit, open circuit, or other electrical condition or off-gas but not entering thermal runaway.* In this instance an internal cell defect does not result in thermal runaway but results in the electrical failure of the cell. This may be by reducing the capacity of the cell relative to its neighbors, creating a dead short or creating an open circuit event.	Thermal Runaway & Mechanical Failure
Hazardous Temperature Condition (Cell)	*High temperature at the cell level during normal operations without thermal runaway.* This hazardous temperature threat is a condition in which cells within a module are exposed to high temperatures just short of thermal runaway. This may be the result of hotspots, an HVAC failure, heavy operation, excessive degradation or increased impedance. Regardless of cause, high cell temperatures pose an increased likelihood of thermal runaway or increasing cell degradation.	Thermal Runaway & Mechanical Failure
Hazardous Temperature Condition (Module)	*High temperature in the module during normal operation without failure / thermal runaway.* At the module level, poor performance of cooling systems may result in cases where a module, sets of modules, or entire racks operate at elevated or uneven temperatures relative to other modules or racks within a system. Cells with manufacturing defects or other environmental considerations may also result in elevated cell and module temperatures.	Thermal Runaway & Mechanical Failure
Hazardous Temperature Condition (Enclosure)	*High temperature in the enclosure during normal operations.* The largest scale of hazardous temperature condition, dangerously elevated container temperatures pose serious risk to system safety. High temperatures throughout the entire enclosure will equate to high temperatures throughout all modules and thus cells, further increasing	Thermal Runaway & Mechanical Failure

Table 1: Detailed Threat Descriptions		
Threat	**Threat Description**	**Threat Category**
	the risk of thermal runaway. Non-uniform thermal management means hot spots may be even hotter than usual. These events may be caused by HVAC failures but may also be the result of poor thermal management of co-located power electronics, intense duty cycles, or environmental conditions such as record high ambient temperatures or fire impingement.	
Electrical Hotspot / Loose Connection	*Loose connections in the system may increase resistance and cause hotspots. Hotspots may form in other ways for unknown reasons. These hotspots will then conduct via bus bars or mechanical contact into cells.* Electrical hotspots within a device may propagate through thermally conductive busbars and materials, resulting in the direct heating of cells. Management of this threat pathway involves proper engineering practices for thermal design, proper commissioning, and maintenance practices to insure proper electrical connections, adequate active or passive thermal monitoring, alarms to stop operation if such conditions are reached and an ability to properly shutdown the system.	Thermal Runaway & Mechanical Failure
Impact	*Something has struck the battery system, sharply or as blunt force, causing mechanical damage or deformation.* This is defined as something striking a system (e.g., inadvertent forklift strike or a vehicle hitting the system as part of a deliberate attack). As physical damage to the batteries can result in either immediate or delayed cell failure and fire, such an event may pose grave risk if unmanaged. The risk of this threat is likely to be greater during maintenance activities when other protection systems are not in service. Maintenance activity-related scenarios fall beyond the scope of this analysis.	External Impact Failures
Water Damage (Flooding)	*The system is flooded with water as a result of liquid cooling system failure.* A failure of the cooling system may lead to flooding of the enclosure. This damage poses two risks, one from the risk of short circuit, and the other from degradation to components and corrosion from exposure to water.	External Impact Failures
Water Damage (Condensation)	*The system is subject to uncontrolled condensation of water via dehumidifier failure, internal condensation of moisture, or from natural reasons.* Whether this is condensate building on cool surfaces which falls onto the system, or the formation of condensate on sensitive parts, the presence of water and moisture within electrical systems is not best practice in these systems (outside of intentional liquid cooling systems or those rated for damp environments). The E5S enclosure includes two separate dehumidifiers which act to reduce the probability of a complete failure of the dehumidifier system.	External Impact Failures
External Fire Impingement	*An external fire that is impinging on the system from outside the containment.* Systems built near combustible materials or equipment are at risk of being exposed to fire should these flammable structures become	External Impact Failures

Table 1: Detailed Threat Descriptions		
Threat	**Threat Description**	**Threat Category**
	involved in fire (examples include power transformers and wildfire threats). The site plan shows that the PCS units are located 8 ft from each pair of enclosures and could pose a potential fire hazard risk to the enclosures. There is also a standby generator located 21 ft from one of the enclosures.	
Dust / Dirt / Particulate Accumulation	*Accumulation of dust, dirt, or particulate that results in an adverse condition inside the system.* Dependent on location and maintenance, the accumulation of dust, dirt, or other particles may result in eventual failure. Examples include reducing the effectiveness of thermal management, causing failure of moving parts or switches, or creating electrical shorts.	External Impact Failures
Human Factors	*An adverse condition caused by the result of human interaction, error, or imperfection.* This broad reaching category is intended to cover any accident directly attributable to human intervention. Human factors include any and all variables that humans induce in the systems they interact with. Examples include a visitor bumping into a button, switch, or wire; a technician dropping a wrench on terminals; and an operator missing a warning signal.	External Impact Failures
Module Cooling or HVAC System Failure	*Mechanical or electrical failure of the module cooling or enclosure HVAC system resulting in high temperatures throughout system.* HVAC system failures are a common occurrence in ESS installations. A failure of the module cooling system or the HVAC system may create clear temperature gradients across the system. The systems provide degree of redundancy to each other.	Control & Prevention System Failure
Sensor Failure	*A sensor inside the system fails, resulting in incorrect reporting of system properties.* As a control system is only as effective as its ability to measure and provide feedback – the failure of a sensor may result in adverse conditions in a system unable to properly measure its own state.	Control & Prevention System Failure
BMS Failure	*Cell / module level monitoring and control fails, resulting in inability to shut down, report adverse conditions, properly monitor, balance, or protect the system resulting in an adverse condition.* Failures may be software related (e.g., hang up in operation), hardware related (e.g., failure of a balancing circuit or loss of a sensor), or a combination of both where the entire system fails.	Control & Prevention System Failure
Enclosure PLC Failure	*Failure of the enclosure PLC controller resulting in adverse condition to the system or inability to detect or protect against adverse conditions under its purview.* The E5S enclosure utilizes a PLC to communicate supervision and control signals between the battery system BMS, HVAC controller, FACP and to the master site controller. While failure of this controller itself is unlikely to result in immediate risk to the system, failure of this controller will likely compromise the ability of the system to communicate its status to the ROCC and control interactions between systems.	Control & Prevention System Failure

Table 1: Detailed Threat Descriptions		
Threat	**Threat Description**	**Threat Category**
Site Control / Balance of Plant / PLC Failure	*Failure of the master site controller or other balance of system controller resulting in adverse condition to the system or inability to detect or protect against adverse conditions under their purview.* While failure of this controller itself is unlikely to result in immediate risk to the system, failure of this controller will likely compromise the ability of the system to adequately shutdown and isolate itself as well as monitor and control interactions between systems. In some cases, if this controller is needed for intervention, failure has likely already occurred or the system is experiencing massive, system wide issues, thus the master site controller may be necessary for adequate isolation from the grid or other AC or DC sources among other actuations. The relative risk of this threat may vary on a site-by-site basis and therefore not fully addressed within the scope of this report.	Control & Prevention System Failure
Shutdown / Isolation Failure	*Failure of the system to shut down or isolate itself when an adverse condition is detected.* This may be the result of a failure of electrical or mechanical protections designed to open power circuits within the system. For the E5S enclosure this may include failure of the battery rack level contactors or other automated disconnects upstream of the enclosure. Failure of this type may require manual human intervention to accomplish system isolation. Each PCS block has a motor operated switch that is capable of disconnecting power upstream and downstream of the block. Additional information related to the relative risk of this threat will be expanded upon in the final HMA.	Control & Prevention System Failure
Hazardous Voltage Condition	*This could include high line voltages, floating ground issues, or other high voltage issues at the cell, module, or rack level.* In this case, the voltage on the batteries is increased or decreased to unsafe levels beyond the voltage limits. A number of issues could cause either scenario. Such scenarios have been directly attributed to historic large scale ESS fires.	Electrical Failure
Ground Fault / Isolation Fault	*This could include localized shorting of cells, shorting between modules, shorting of entire racks or systems and ground fault shorting.* Unintended ground faults and insulation faults resulting in shorts that produce adverse, high current events. Similar to short circuiting, these events have been directly attributed to historic large scale ESS fires.	Electrical Failure

Table 2: Detailed Preventative Barrier Descriptions	
Barrier	**Preventative Description**
Passive Module Protections	*Module fuse which may open the circuit in the case of failure as well as general resilience of design to withstand adverse electrical conditions.*

Table 2: Detailed Preventative Barrier Descriptions	
Barrier	**Preventative Description**
	In cases where the circuit is unable to adequately isolate itself, the final barrier to avoiding catastrophic failure is passive circuit elements. Passive protection is provided by the module fuse which may open individual modules prior to failure. Depending on the nature of the failure, these elements may have mixed success in achieving these goals. The final passive protection barrier resides in the module itself.
Liquid Cooling System	*The liquid cooling system is an active cell protection which may prevent thermal runaway propagation.* Active cell protections include any type of actively monitored or controlled mechanism intended to protect against the effects of thermal runaway, whether it be actively preventing the cell from entering thermal runaway or actively mitigating thermal runaway once it occurs. For the E5S enclosure, this includes the liquid cooling system.
Enclosure Dehumidification System	*The enclosure's dehumidification system acts to prevent the buildup of condensation that may pose a short circuit hazard.* The E5S enclosure is provided with two dehumidifiers, one located on each side of the fire separation. The operation of the dehumidifiers are initiated by a humidity sensor located on each side of the fire separation. Humidifiers are powered from a separate auxiliary feed and will remain powered regardless if the enclosure is disconnected from DC power.
Direct Injection Clean Agent System	*The direct injection clean agent system is an active cell protection which may prevent thermal runaway propagation.* Active cell protections include any type of actively monitored or controlled mechanism intended to protect against the effects of thermal runaway, whether it be actively preventing the cell from entering thermal runaway or actively mitigating thermal runaway once it occurs. For the E5S enclosure, this includes the direct injection clean agent systems. This system is activated by activation of two smoke detectors or by the manual release located on the outside of the E5S enclosure. The system will continue to operate, discharging agent to all cells, until the agent is exhausted. The potential effectiveness of this barrier is demonstrated in the UL 9540A installation level testing.
Cell Thermal Abuse Tolerance	*Ability of the cells to withstand thermal abuse without going into failure themselves.* Thermal abuse tolerance applies to the ability of the chemistry in question to fail when exposed to high temperatures. It is typically not considered a strong barrier without sufficient testing to demonstrate. Both the cell and module proposed for the E5S enclosure are UL 1973 listed which includes testing for thermal abuse tolerance.
Cell Quality Control	*Overall quality of the cell such that internal defects are minimized, and cells maintain rigidity and shape during operations. Also includes tight tolerances with respect to degradation.* This barrier is intended as a catch all for considerations related to cell quality. This is likely to be outside the control of the end user of the system but covers the overall reliability of the cells with respect to internal failures and faults that may result in adverse conditions.

Table 2: Detailed Preventative Barrier Descriptions	
Barrier	**Preventative Description**
BMS Control	*Includes monitoring and shutdown/isolation capabilities of the affected BMS / module or system.* BMS Control includes aspects of BMS Shutdown / Disconnect but also includes overall effectiveness of monitoring such that proactive measures may be taken, or warnings given, indicating imminent failure or adverse conditions. Utilized as a barrier on multiple threats, this barrier is evaluated differently in each case based on the algorithmic response to the threat or failure in question.
Temperature Monitoring and Alarms	*Thermal monitoring within the container.* This barrier is the ability of the battery system or BMS to detect adverse thermal conditions within itself and alarm those issues outward. Four temperature sensors are provided within each module. The BMS will initiate an automatic shutdown when a hazardous temperature condition is detected.
System Shutdown / Disconnect	*Ability of system to actively shut itself down or disconnect itself. This is the aggregate of the BMS ability as well as physical disconnects and the Balance of System controller's ability to shut down.* This barrier may be approached from two perspectives, with the first the ability of the system to truly shut off only the affected and responsible operations when such conditions are detected. This shutdown will stop ohmic and electrochemical heating thus stopping heat generation and may also increase the temperature at which thermal runaway would occur (by stopping internal heat generation). The second approach involves shutting down the entire system. The BMS system is capable of automatically disconnecting individual battery racks. Remote emergency manual system shutdown of the enclosure from the ROCC can only be accomplished using disconnects located beyond the E5S enclosure. A manual DC disconnect is also available within the enclosure. The strength of this barrier will be expanded upon in the final HMA.
Preventative Maintenance and Commissioning	*Proper maintenance and monitoring of the system in conjunction with adequate commission and site acceptance testing to reduce likelihood of loose connections or other transportation or construction defects.* Preventative Maintenance consists of the normally scheduled preplanned maintenance required for operation such as periodic inspections for function and operating limits and the necessary upkeep required for continued operation as well as the prompt repair of failures and failing components. Commissioning refers to the process of bringing the system online, performing inspections of the built system to ensure proper compliance with operating parameters, and the shakedown of “bugs” and issues from construction to normal operation. Through these processes, the system is brought to and maintained in good working order.
Passive Circuit Protection and Design	*Breakers and fuses which may open the circuit in the case of failure and general resilience of design to withstand adverse electrical conditions.* The E5S enclosure includes a passive fuse for each battery rack and at the main DC disconnect.
Cell Electrical Abuse Tolerance	*Ability of the cell to withstand electrical abuse such as overcharge, over discharge, high currents, or other adverse electrical abuse.*

Table 2: Detailed Preventative Barrier Descriptions	
Barrier	**Preventative Description**
	The ability of the individual cells to withstand electrical abuse such as short circuit, overcharge, and overcurrent events without resulting in adverse conditions. As no testing standard yet exists to quantify the ability of the cell to withstand electrical abuse, this barrier is evaluated as weak
Redundant Failure Detection / System Intelligence	*Ability of system to determine a sensor has failed, to operate safely without that sensor to shut down, or operate safely indefinitely without sensor. This may include Checksums, additional sensors, or the ability to pull data from other sensors.* This barrier is highly dependent on the sensor in question as well as the design, architecture, and operation of the system as a whole and the evaluation of the data collected within the confines of the system.
Human Factors / Process Control	*Quality control or other processes put in place to prevent mishandling of systems that may result in adverse or hazardous conditions or mishandling.* A catchall barrier that includes all possible failures and adverse conditions brought about by human interaction with the system. It also includes failures related to process and flow separate from the control system of ESS itself. This could be as simple as a technician dropping a wrench across the terminals or as complex as sophisticated maintenance procedure which fails to adequately address an otherwise trivial detail, such as failure to check the tightness of unreachable bolts or clean unexposed terminals. The relative strength of this barrier is assumed to be in alignment with industry norms.
Container / Structural Resiliency	*Resiliency of the system and container of the system to withstand impacts or strikes.* The enclosure envelope is assumed to be effective to protect against basic vandalism or low speed, accidental vehicle impacts such as construction equipment as well as high winds, hail, seismic vibrations, and other environmental forces.
Module Resiliency	*Resiliency of the individual modules to withstand impacts, shocks, or other mechanical abuse.* Similar to cell abuse tolerance, this barrier covers the overall strength and rigidity of a battery module as it relates to the ability of the module to withstand both impacts and shocks as well as the noise, vibration, and harshness.
Cell Physical Abuse Tolerance	*Ability of the cell to withstand thermal, physical, or mechanical abuse.* This barrier considers the ability of a cell to withstand physical, thermal, or mechanical damage without resulting in an adverse condition. As all lithium ion battery chemistries have shown susceptibility to physical damage such as penetration and crush, this barrier is likely to be considered weak, depending on the threat faced. The proposed cell and module have been certified to UL 1973 which includes physical abuse testing. These include vibration, shock, crush, static force, impact, and drop impact testing. The strength of this barrier is assessed as strong when the degree of abuse is within the bounds of UL testing but may be weaker when these bounds are exceeded.
Humidity Monitoring	*Monitoring within the container which may detect high humidity, water condensation or water leakage.*
System Maintenance	*Proper preventative maintenance to minimize the impact of adverse, long term or slow acting environmental effects resulting in degradation.* Includes normally scheduled maintenance required for operation including periodic inspections for function and operating limits, replacement of expendable parts, and

Table 2: Detailed Preventative Barrier Descriptions	
Barrier	**Preventative Description**
	any necessary upkeep required for continued operation. Also includes prompt repair of failures and failing components.
SME Training	*Proper training procedures, availability of subject matter expertise and system competence, and clear jurisdictional hierarchy for managing situations.* Though required by fire codes such as NFPA 855, subject matter expert (SME) remains an undefined term and the quality and title of SMEs across the industry varies wildly. In addition to the undefined term, there is no nationally recognized standard or methodology for training or credentialing subject matter experts. In some cases, the SME may be more critical to the response of an ESS emergency than the first service, because the safety of the first responders and fire fighters also depends on the SME. This role should be evaluated carefully by all stakeholders when selecting an SME.
Voltage Monitoring	*Overall effectiveness of the voltage monitoring scheme of the system. Includes resilience to errors, error checking, and other measurement intelligence.* This includes adequate measurement of voltage throughout the system coupled with checks or redundant measurements such that a sensor failure cannot drive the system to an adverse condition. This includes monitoring of module, rack, and bus levels DC voltages and any intermediary voltages.
Insulation Monitoring	*Continual, or active, monitoring of insulation integrity, ground versus float voltage, and other practices to prevent insulation or isolation degradation.* Insulation monitoring is a common electrical maintenance best practice. Degradation of insulation for any reason runs the risk of current related failures anywhere in the system. This includes not just wire insulation but isolation on components and effectiveness of ground isolation during normal operation.

APPENDIX D – CONSEQUENCE AND MITIGATIVE BARRIER DESCRIPTIONS

Table 1: Detailed Consequences Descriptions	
Consequence	**Consequence Description**
Cell / Module Combustion	*A battery cell or module has failed and is now producing flame or combusting.* A single cell failure resulting in combustion and flame is likely the result of thermal runaway. While several mitigating barriers exist to prevent this scenario from reaching its natural conclusion, should those barriers fail, it is possible this consequence will continue, evolving into any of the consequences included in this analysis. Spread to other nearby cells or modules may continue the propagation of failure throughout the system
Multi-Module / Rack Fire	*Multiple modules have begun producing flame or combusting.* Fire within multiple modules or racks. Fire at this scale may be the result of propagation from a smaller event. Fire at this scale will be more dependent on the fire department response. Defensive postures may be needed to protect external exposures. A fire of this magnitude is expected to continue burning for several hours. This fire scenario is beyond the fire events experienced in UL 9540A testing for the E5S enclosure.
Fire Spread Beyond Enclosure Fire Partition	*A fire within the system has spread from one side of the enclosure fire rated partition to the modules/rack and equipment on the opposite side within the same enclosure.* In this scenario, the fire event has spread beyond the fire partition that subdivides the E5S enclosure, subsequently involving the modules/racks and other equipment on the opposite side of the enclosure. This fire scenario is beyond the fire events experienced in UL 9540A testing for the E5S enclosure.
Fire Spread Beyond Enclosure	*A fire within the system has spread beyond the enclosure to adjacent ESS enclosures or other structures.* In this case, fire has likely compromised the entire or a large portion of the interior space of the enclosure and has now breached the container, posing immediate risk to adjacent equipment or facilities. This scenario may occur even if the fire does not compromise the enclosure fire partition. Defensive firefighting is likely required to mitigate this incident. A fire of this scale may burn for several hours or days. ASHREA data for the nearest airport at Albuquerque International shows 1% extreme wind speed shows a wind speed of 28.2 mph and high temperatures of 95.2º F. The overall site is relatively flat and a defensible space is recommended to be maintained around enclosures to reduce wildfire risk. Based on the project site plan, the E5S enclosures are grouped in side-by-side pairs with 3.5 feet of space between each enclosure. Each pair is then spaced 21.75 ft from the next pair in groups totaling 5 pairs (10 E5S enclosures). The site consists of 4 total groups of enclosures separated by a minimum of 40' of space between them. If a fire spreads beyond an enclosure, it is highly likely the pair will become involved. It is recommended that defensive firefighting be provided to mitigate further spread to adjacent pairs of enclosures. Fire modeling is being conducted to determine the likelihood of a fire spreading beyond that. The Final HMA report will be updated to include the results of the analysis.
Cell Off-Gassing / Explosions	*A cell or multiple cells have failed or entered thermal runaway and is now producing off-gas.* UL 9540A testing indicates that the cell off gasses include hydrogen, carbon monoxide, methane and other flammable hydrocarbons. When mixed with oxygen from the air, a flammable mixture may be formed. As such, this event may pose even greater risk than a single cell combustion, as the ability of batteries to maintain high temperatures in excess of autoignition temperatures for hours is well documented and the electrical nature of the systems adds additional ignitions sources. The cells utilized for the E5S enclosure may

	possess enough electrolyte, and ultimately gas generation potential, to create a flammable environment from only a single cell.
Accumulation of Off-Gasses / Delayed Explosions	*A cell or multiple cell failure which may or may not have propagated has resulted in the accumulation of potentially explosive off-gas within the enclosure.* Even with a single cell, long after the risk of propagating failure has passed, off-gas may continue to linger in the area, especially within the enclosure. This gas may continue to pose deflagration risk. Even cooled or extinguished batteries may emit gas several hours following an event. The lack of ventilation within the enclosure means the ability to exhaust this gas without putting personnel into harm's way is practically nonexistent.
Balance of System Fire	*A fire that either is initiated in or results in the involvement of a balance of system fire such as wire insulation, electrical components, or plastic inside the system.* In this instance, a small fire results in damage to the balance of system, including wiring insulation, bus bars, plastic containment or other component or material. Such damage may pose significant risk as compromised wiring or components may result in arcing, shorting, or other high energy event or act as ignition source causing delayed fire or explosion.
Environmental / HAZMAT Issues	*A large-scale system fire has resulted in an environmental or hazardous material incident which requires hazardous material response.* Examples include toxic smoke / gas plumage, contamination of firefighting runoff water in a sensitive area, or leftover energetic hazardous materials which may require special handling. These issues may be an active concern throughout the initial fire / thermal runaway incident or may be addressed post initial incident.

Table 2: Detailed Mitigative Barrier Descriptions

Barrier	Mitigative Barrier Description
Enclosure Smoke Detection	*Activation of the enclosure's smoke detection system and communication via the Fire Alarm Control Panel (FACP). System activation provides both situational awareness to facility operators, personnel in the vicinity of the enclosure and first responders, as well as activation of the enclosure's direct injection clean agent system.* This barrier provides situational awareness of an emerging situation to facility operators and first responders. The effectiveness is based on the ability of the system and site to provide information and clarity of the failure. Poor situational awareness may weaken subsequent barriers. Effective use of the information provided by this system is dependent on proper annunciation of this data on site or the availability of this data to first responders and operations personnel. Activation of the smoke detection system will initiate the enclosure fire alarm notification device to facilitate personnel evacuation from the immediate vicinity of the enclosure. Communication of the fire alarm signal from the enclosure's FACP to the site's FACP may be used to initiate site wide notification of the fire event. Detection of smoke within the enclosure by two or more detectors will result in activation of the direct injection clean agent system. Depending upon the nature of the failure scenario, this system may act to reduce or limit the likelihood of continued propagation of a thermal event.

Enclosure Gas Detection System	*Activation of the enclosure's gas detection system and communication of alarm signal to the SCADA system. System activation provides situational awareness to facility operators, personnel in the vicinity of the enclosure and first responders.* This barrier provides situational awareness of an emerging situation to facility operators and first responders. When activated the gas detection system raises an alarm in the ROCC and will activate the enclosure fire alarm notification device to facilitate personnel evacuation from the immediate vicinity of the enclosure. Communication of gas detector data to emergency and first responders will require interface with the ROCC. The strength of this barrier may vary on a site-by-site basis and requires coordination with the team.
Occupant Notification	*Activation of the alarm notification device on the exterior of the enclosure and activation of the facility's site wide alarm system if provided.* This barrier provides situational awareness of an emerging fire or gas related situation to occupants in the area adjacent to the enclosure and in the wider facility (if a site wide occupant notification system is provided). Occupants are expected to evacuate the immediate area upon alarm system activation. The strength of this barrier may vary depending upon the quality of employee and site visitor training. The strength of this barrier may vary on a site-by-site basis and therefore not fully addressed within the scope of this report.
BMS Data Availability	*Includes BMS measurements available to first responders, ROCC, or other SMEs. Effectiveness based on what is detected and how accurate, how this information is being conveyed, and robustness of sensors in case of failure.* In the event of a failure event, BMS data may be available via the ROCC or otherwise communicated to first responders. This information may provide insight into the current conditions of the system (e.g., temperature of cells / modules, SOC, voltage trends, etc.) – provided the system is still online – or the state of the system prior to loss of measurements. This barrier provides situational awareness of an emerging situation to facility operators and first responders. The effectiveness is based on the ability of the system and site to provide information and clarity of the failure. Poor situational awareness may weaken subsequent barriers. Effective use of the information provided by this system is dependent on proper annunciation of this data on site or the availability of this data to first responders and operations personnel.
Direct Injection Clean Agent System	*Activation of the direct injection clean agent system may limit or reduce the rate of a propagating thermal runaway event.* This system is activated by smoke detector operation (two or more detectors). The direct injection clean agent may limit or reduce the rate of a previously occurring propagating thermal runaway event.
Deflagration Protection	*Activation of the enclosure's deflagration venting system.* Deflagration or explosion as a result of combustion, expansion, or detonation, poses severe risks to life and property near an ESS. UL 9540A testing indicates that the cell off gasses include hydrogen, carbon monoxide, methane and other flammable hydrocarbons. When mixed with oxygen from the air, a flammable mixture may be formed. The E5S enclosure has been provided with a deflagration vent design in accordance with the requirements of NFPA 68. The system has been subject to both UL 9540A installation level testing and bespoke deflagration testing. The system has been primarily designed to protect from an off-gassing event involving three cells.

Thermal Isolation (Enclosure Insulation)	*Passive thermal propagation protection provided by insulation installed on the boundaries of the enclosure.* The insulating panels provided on the enclosure walls is anticipated to reduce conduction to the exterior surface of the enclosure thusly retarding fire spread to adjoining enclosures. The assessed strength of this barrier for the E5S enclosure is informed by both UL 9540A and bespoke fire testing. These will be analyzed and included in the final HMA report.
Thermal Isolation (Enclosure Fire Separation)	*Passive thermal propagation protection provided the enclosure's fire separation.* The enclosure's fire separation subdivides the enclosure into two separate fire compartments. This separation provides a strong barrier to limiting a flaming fire event to half of the enclosure. The assessed strength of this barrier for the E5S enclosure is informed by bespoke fire testing. These will be analyzed and included in the final HMA report.
Thermal Isolation (Module / Rack Separation)	*Passive thermal propagation protection provided by physical separation between modules within a rack and physical separation between racks within the enclosure.* The degree of separation provided between modules within rack and between racks acts to retard the rate of thermal runaway / fire propagation. This barrier is assessed to be relatively weak for most flaming fire scenarios but stronger for non-flaming thermal runaway scenarios. The assessed strength of this barrier for the E5S enclosure is informed by both UL 9540A and bespoke fire testing. These will be analyzed and included in the final HMA report.
Facility Design and Siting	*Placement of the facility such that adverse environmental effects such as flooding, vehicle impact, and fire impingement are mitigated or avoided. The strength of this barrier is dependent upon the site-specific aspects of the facility layout.* This barrier is intended to include analysis of the system in its location with respect to localized environmental hazards, adjacent structures, fire loads, and personnel exposures, and other generic environmental threats either to the system as posed by the environment or to the environment as posed by the system. While a specific spacing may be suitable for most ESS, it may not be sufficient spacing from a large fuel storage depot or an ambulatory care facility. Further, proper siting should include the type of environment the system is built in such as a flood plain, a high traffic area, a wetland, or an area prone to fire. The E5S enclosures are grouped in side-by-side pairs with 3.5 feet of space between each enclosure. Each pair is then spaced 21.75 ft from the next pair in groups totaling 5 pairs (10 E5S enclosures). The site consists of 4 total groups of enclosures separated by a minimum of 40' of space between them. If a fire evolves to the point it spreads beyond an enclosure, it is highly likely the pair will become involved. It is recommended that defensive firefighting be provided to mitigate further spread to adjacent pairs of enclosures. The additional separation between the pairs and the groups of enclosures helps to mitigate the potential for fire to spread throughout the site. The site is considered remote and not anticipated to have public traffic that could pose physical damage risk to the enclosures.
Emergency Response Plan / First Responders	*System operator plan to handle any and all emergency events. A site-specific emergency response plan should be developed. Effectiveness based on level of the subject matter expert (SME) / first responder training, knowledge of the specific ESS undergoing failure, coordination with fire department, etc.* First responders refer to site personnel, corporate employees, local technicians, and SMEs who may be the first to detect or respond to failure or fault in the system and alert fire services. The term first responders in this case does not refer to fire fighters or other fire service personnel, but to those who will be reporting the event or directing the fire

	service in regard to the risks posed by the system. The guidance from these individuals, as well as the information contained in the emergency response plan, will serve as the initial human response to the incident and have the greatest chance of containing the incident, if it is containable, to a reduced state. Depending on time to detection, along with time to first response and fire service response, the incident may have progressed through multiple consequence pathways, as single cell failure can propagate to adjacent modules and beyond in a matter of minutes. The ERP will be reviewed and the strength of this barrier will be expanded upon in the final HMA.
Fire Service Response	*Fire department response including active firefighting suppression. Effectiveness based on level of department knowledge and training to effectively respond both offensively and defensively during an ESS incident.* This barrier includes all aspects of the fire service response including the personnel, resources, knowledge, and overall comfort level brought to bear on the scene. Current industry training and emergency response planning point toward automatic dispatch of multiple trucks or departments/stations for ESS emergencies or multiple alarms in some jurisdictions. Response time, access, fire water supply and situational awareness (e.g., Detection Systems) will act as a multipliers, resulting in decisions which may save the currently impacted or adjacent systems or result in the loss of the entire facility. SFCFD does not have a HAZMAT team but utilizes the City of Sante Fe Fire Department with a response time of 24 minutes.

APPENDIX E – BOW TIE MODEL DIAGRAMS

Figure E-1 – Thermal Runaway and Mechanical Failure Threat Pathways

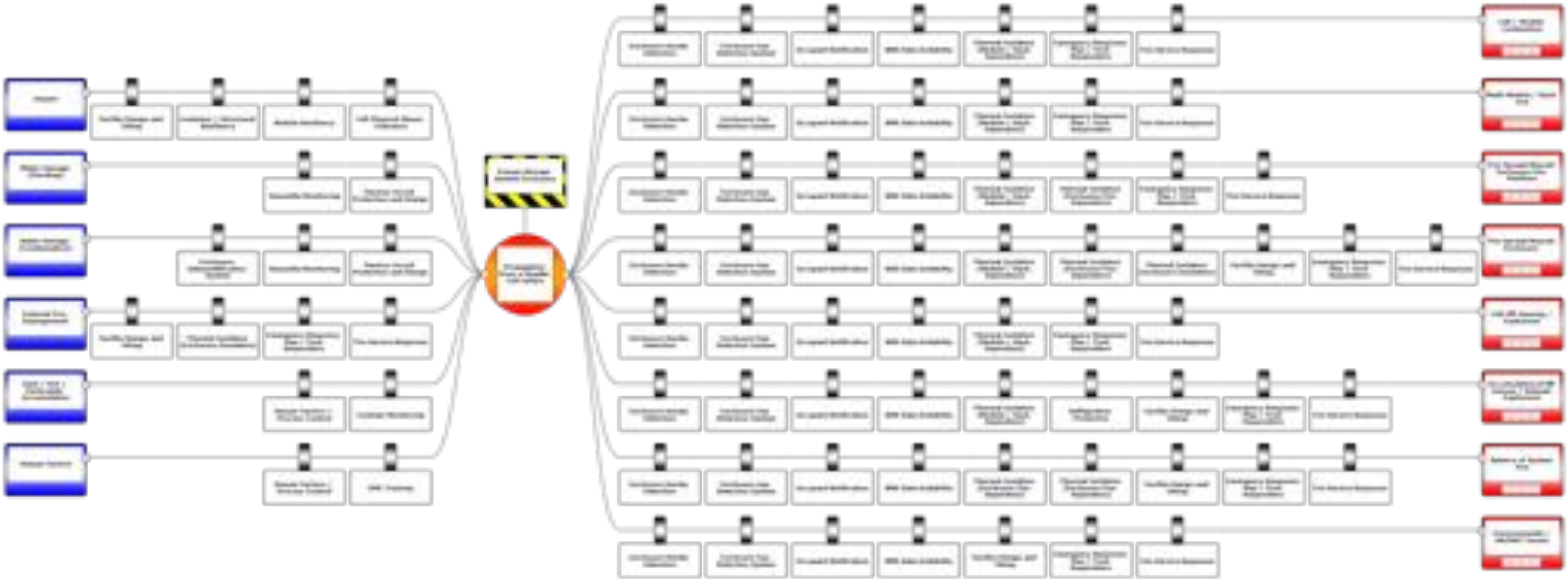

Figure E-2 – External Impact Failures Threat Pathways

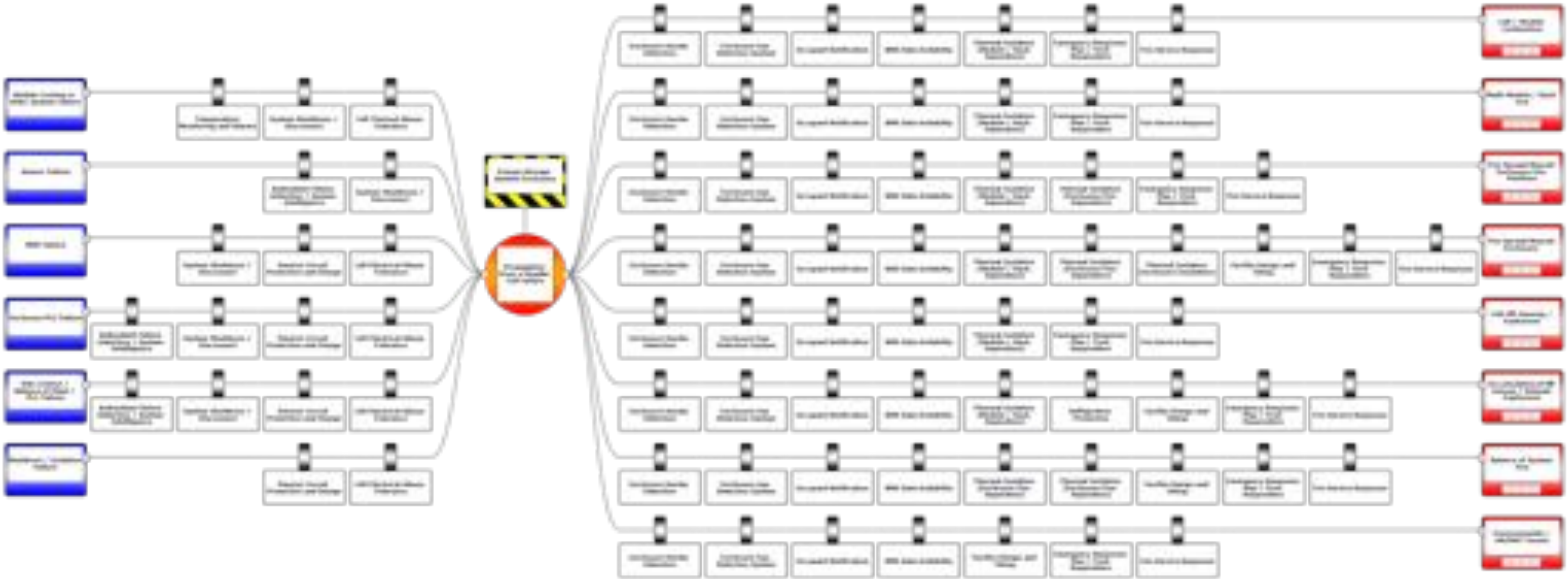

Figure E-3 – Control and Prevention System Failure Threat Pathways

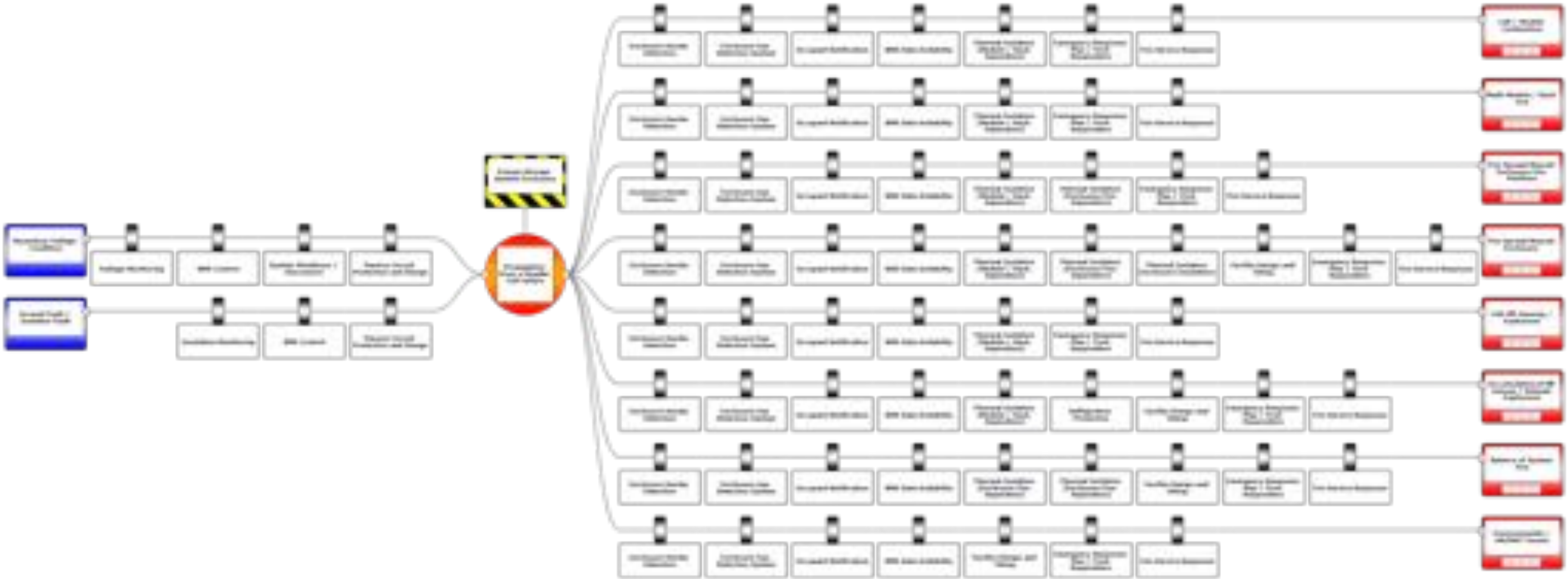

Figure E-4 – Electrical Failure Threat Pathways

APPENDIX F – UL 9540A FIRE TEST RESULTS

CELL TEST REPORT
ULL 9540A
Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems (AACD)

Project Number................................:	**4790746849**
Date of issue ....:	**2023-07-07**
Total number of pages...................:	**34**
UL Report Office ....:	UL Solutions
Applicant's name............................:	SAMSUNG SDI CO LTD
Address ....:	428-5 GONGSE-DONG GIHEUNG-GU YONGIN-SI, GYEONGGI-DO 446-577 Republic of Korea
Test specification:	4th Edition, Section 7, November 12, 2019
Standard ....:	UL 9540A, Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems
Test procedure ....:	7.1, 7.2, 7.3.1, 7.4, 7.6.1, 7.7
Non-standard test method ....:	N/A

General disclaimer:

The test results presented in this report relate only to the sample tested in the test configuration noted on the list of the attachments.

UL LLC did not select the sample(s), determine whether the sample(s) was representative of production samples, witness the production of the test sample(s), nor were we provided with information relative to the formulation or identification of component materials used in the test sample(s).

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Cell level information	
Model No ....:	CP1495L101+
Ratings (Vdc, Ah) ....:	3.68 Vdc, 145 Ah
Chemistry of test item………………:	$LiNiCoAlO_2$
Original Equipment Manufacturer (OEM):	SAMSUNG SDI CO LTD
Branding Manufacturer (if not OEM):	N/A
Was the cell certified? …………………………..:	Yes
Standard test item certified to …………..:	UL 1973 (File Number: MH64496)
Organization that certified test item …….:	UL
Average cell surface temperature at gas venting, °C:	166
Average surface temperature at thermal runaway, °C:	178
Gas Volume (L):	423
Lower flammability limit (LFL), % volume in air at the ambient temperature	8.04
Lower flammability limit (LFL), % volume in air at the venting temperature	6.74
Burning velocity (S_u) cm/s:	86.40
Maximum pressure (P_{max}) psig:	105.3

Cell Gas composition

Gas	Measured %
Hydrogen	32.7 %
Carbon monoxide	40.9 %
Methane	15.43 %
Ethylene	0.56 %
Ethane	1.06 %
Carbon dioxide	9.2 %
Propene (Propylene)	0.04 %
Propane	0.03 %
C4 Total	0.05 %
C5 Total	0.01 %
Benzene	0.06 %
Total	**100 %**

Cell failure test method performed (summary of method and test clause):

- ☒ External heating using thin film with 4°C to 7°C thermal ramp.
- ☐ Nail Penetration
- ☐ Overcharge
- ☐ External short circuit (***X*** Ω *external resistance*)
- ☐ Flow Battery with 2 active electrolyte methods
- ☐ Flow Battery with 1 active electrolyte methods
- ☐ Others

Description of method used to fail cells if other than external thin film heater with thermal ramp, : **N/A**
Summary of testing:
~~**Performance Criteria in accordance with Clause 7.7 and Figure 1.1:**~~ ~~[ ] Thermal runaway was not induced in the cell; and~~ ~~[ ] The cell vent gas did not present a flammability hazard when mixed with any volume of air, as determined in accordance with ASTM E918 at both ambient and vent temperatures.~~
Necessity for a module level test
[X] The performance criteria of the cell level test as indicated in 7.7 of UL 9540A 4th edition has not been met, therefore a module level testing in accordance with UL 9540A will need to be conducted on a complete module employing this cell. **[ ]** The performance criteria of the module level tests as indicated in 7.7 of UL 9540A 4th edition has been met, therefore a module level testing in accordance with UL 9540A need not be conducted.

Testing Laboratory information		
Testing Laboratory and testing location(s):		
Testing Laboratory:	SAMSUNG SDI CO LTD	
Testing location/ address .... :	Samsung Sdi Samnam Myeon Ulju Gun Ulsan 689-701 Republic of Korea	
Tested by (name, signature)....................... :	YongHee Yun	
Witnessed by (for 3rd Party Lab Test Location) (name, signature) .... :	BeomSeok Hong	
Project Handler (name, signature)............. :	BeomSeok Hong	
Reviewer (name, signature) …………….:	Sean Yang	
Gas Analysis Testing Laboratory:		
Burning velocity Testing location/ address.. :	UL Solutions / 333 Pfingsten Road Northbrook, IL 60062 USA	
Lower Flammability Limit and Explosion Severity Testing location/ address... :	UL Solutions / 333 Pfingsten Road Northbrook, IL 60062 USA	
Project Handler (name, signature)............ :	Robert Hollis	
Reviewer (name, signature) …………….:	Chris Jones	

List of Attachments (including a total number of pages in each attachment):
Attachment A: Cell Conditioning (Charge/discharge) Profiles - (*Pages **16** through **20***)
Attachment B: Cell Instrumentation Photos - (*Pages **21** through **22***)
Attachment C: Cell Temperature Profiles during testing - (*Pages **23** through **25***)
Attachment D: Cell Testing Photos - (*Pages **26** through **30***)
Attachment E: Cell Test Datasheets - (*Pages **31** through **31***)
Attachment F: Cell vent gas test chamber photo and profile of chamber gas analysis (O_2 and Pressure) – (*Pages **32** through **33***)
Attachment G: Certification Requirement decisions - (*Pages* **34** *through* **34)**

Photo of cell:

<Top>

<Overall>

Test Item Charge/Discharge Specifications:	
• **Charge current, A:**	47.3
• **Standard full charge voltage, Vdc:**	4.15
• **Charge temperature range, °C:**	0 to 60
• **End of charge current, A:**	29
• **Discharge current, A:**	47.3
• **End of discharge voltage, Vdc:**	2.7
• **Discharge temperature range, °C:**	0 to 60

Test item particulars ....:	
Possible test case verdicts:	
- test case does not apply to the test object...........:	N/A
- test object does meet the requirement ....:	P (Pass)
- test object does not meet the requirement...........:	F (Fail)
- test object was completed per the requirement...:	C(Complete)
- test object was completed with modification……:	M(Modification)
Testing...:	
Date of receipt of test item ....:	2023-02-21
Date (s) of performance of tests ....:	2023-02-21 to 2023-02-22, 2023-03-27 to 2023-03-28
General remarks:	
"(See Enclosure #)" refers to additional information appended to the report. "(See appended table)" refers to a table appended to the report. **Throughout this report a point is used as the decimal separator.**	
Manufacturer's Declaration of samples submitted for test:	
The applicant for this report includes samples from more than one factory location and a declaration from the Manufacturer stating that the sample(s) submitted for evaluation is (are) representative of the products from each factory has been provided ....:	☒ **Yes** ☐ **Not applicable**
Name and address of factory (ies) ....:	1. SAMSUNG SDI CO LTD 163 Bangudae-ro, Ulju-gun,Ulsan, Ulsan, 689-701, Republic of Korea 2. Samsung SDI-ARN(XI'AN) Power Battery Co Ltd No 2655 BiYuan 3rd road, Xi'an, Shaanxi Sheng, 710399,China
General product information and other remarks: CP1495L101+ is a rechargeable li-ion battery cell manufactured by SAMSUNG SDI CO LTD. The cell is rated for 3.68 Vdc, 145 Ah. See table Critical components information for details. The suffix "+" is a placeholder to identify the customer of Samsung SDI, who purchases the cell tested in this report. Samsung SDI confirmed that cells with different suffixes will have the same cell design. The sample tested was CP145L101A.	

UL 9540A, Edition 4,			
Clause	Requirement + Test	Result - Remark	Verdict

5.0	**CONSTRUCTION**		**Verdict**
5.1. 5.4	**Cell/Stack Construction**		—
5.1.1, 5.4.1	Generic Chemistry:	Li-ion ($LiNiCoAlO_2$)	—
	Electrolyte Chemistry:		—
	Flow Battery Electrolyte No. 1 Chemistry:	N/A	—
	Max volume of system electrolyte No. 1, L:	N/A	—
	Flow Battery Electrolyte No. 2 Chemistry:	N/A	—
	Max volume of system electrolyte No. 2, L:	N/A	—
	Separator Melt Temperature, °C:		—
	Format: Cylindrical /Prismatic /Pouch Flow Battery Stack	Prismatic	—
	Overall Dimensions, mm		—
	Cell Weight, g		—
5.1.2	Cell Certification:	Certified	—
	Standard Used for Cell Certification:	UL 1973 , Appendix E File Number: MH64496	—
	Organization that Certified Cell:	UL Solutions	—
5.1.1, 5.4.1	Cell/Stack Ratings: • Nominal Voltage, Vdc •Nominal Capacity, Ah	3.68 Vdc 145 Ah	— —
5.4.1	Flow Battery: No. of Cells per Stack:	N/A	—
	Flow battery system manufacturer:	N/A	—
	Flow battery system model:	N/A	—
	Flow battery system ratings, Vdc, Ah:	N/A	—
5.4.2	Flow battery system certified to UL 1973:	N/A	—
	Organization that certified flow battery system:	N/A	—
6.0	**PERFORMANCE**		**Verdict**
6.1	**General**		
7.2	**Samples**		
7.2.1	Samples conditioned through charge discharge cycling a minimum of 2 cycles.	See Attachment A for profiles See Table 1 for specifications	C
7.2.2	100% SOC and stabilize from 1h to 8 h before testing		

UL 9540A, Edition 4,			
Clause	Requirement + Test	Result - Remark	Verdict

7.2.3	Pouch Cells constrained per end use during testing.		C
7.3	**Determination of thermal runaway methodology**		
7.3.1	**General**		
7.3.1.1	Ambient indoor laboratory conditions: 25 ±5°C (77 ±9°F) ≤50 ±25% RH at the initiation of the test.	See Attachment C and E	M
7.3.1.2	Heat the cell to thermal runaway by externally applied flexible film heaters	See Attachment B	C
	Heater Dimension	98.85 mm x 157 mm	
	A surface heating rate of 4° C (7.2° F) to 7° C (12.6° F) per minute was applied to the cell.	See Attachment C, D, and E See Table 4.	C
	Maximum surface end point temperature, °C	In accordance with Certification Requirement Decision dated on 2020-05-20, no holding temperature used for the test. Please refer to Attachment G.	M
	The following method(s) was employed to cause thermal runaway: ☐ Mechanical (e.g. nail penetration); ☐ Electrical stress in the form of overcharging, ☐ Electrical stress in the form of over discharging ☐ Electrical stress in the form of external short-circuiting ☐ Use of alternate heating sources (e.g. oven). ☐ Other (explain)	Only external heating using film heaters was used.	N/A
7.3.1.3	Detail of test method when using another cell abuse method to initiate thermal runaway	See Attachment E	N/A
7.3.1.4	Monobloc batteries such as a lead acid battery		N/A
7.3.1.5	Estimated surface temperature at which internal short circuiting within the cell will occur that could lead to a thermal runaway condition.		N/A
7.3.1.6	The cell was heated until thermal runaway has occurred.	Refer to Attachment C	C
	Another external heating method was used to cause cell thermal runaway		N/A
7.3.1.7	The cell's exterior surface temperature was measured	See Attachment B	C
7.3.1.8	The temperature at which the cell case vents due to internal pressure rise was documented.	See Table 3 and 4 See Attachment C, D and E	C

Clause	Requirement + Test	Result - Remark	Verdict
7.3.1.9	The temperature at the onset of thermal runaway was documented.	See Table 3 and 4 See Attachment C, D and E	C
	If cell venting occurs first, the cell was heated continuously until thermal runaway occurs.	See Attachment C	C
7.3.1.10	When using methods other than the heater method, the stresses were applied to the cell until thermal runaway occurs.		N/A
7.3.1.11	3 additional samples were tested using the same method and exhibited thermal runaway	See Table 3, 4 and 5 See Attachment C, D and E	C
7.4	**Cell vent gas composition test**		
7.4.1	Cell vent gas was generated and captured by forcing a cell into thermal runaway with the methodology developed in 7.3, inside a pressure vessel	Size of pressure vessel used: 82 L Refer to Attachment F	C
	The test was initiated with an initial condition of atmospheric pressure and less than 1% oxygen by volume.	Refer to Attachment F Atmospheric pressure (psig): 0.96	C
		Oxygen concentration measured (% volume): < 0.55	
		Inert gas used: Nitrogen	
7.4.2	Cell vent gas composition was determined using Gas Chromatography (GC)	Refer to Table 8 Refer to Attachment F	C
	Hydrogen gas was measured	Refer to Table 8	C
	The initial atmospheric conditions prior to testing were noted.	Refer to Table 3 Refer to attachment C and F	C
7.4.3	The lower flammability limit of the cell vent gas was determined on samples of the synthetically replicated gas mixture in accordance with ASTM E918, testing at both ambient and cell vent temperatures.	Refer to Table 9 and 10	C
7.4.4	The gas burning velocity of the synthetically replicated cell vent gas was determined in accordance with the Method of Test for Burning Velocity Measurement of Flammable Gases Annex in ISO 817.	Refer to Table 9 and 10	C
7.4.5	P_{max} of the synthetically replicated cell vent gas was determined in accordance with EN 15967.	Refer to Table 9 and 10	C
7.6	**Cell Level Test Report Information**		

UL 9540A, Edition 4,			
Clause	Requirement + Test	Result - Remark	Verdict
7.6.1	Minimum information provided in the report for items a) through m)		C
7.6.2	Minimum information of items a) through k) was provided in the report for flow battery		N/A
7.7	**Performance – cell level test**		
7.7.1	a) Thermal runaway cannot be induced in the cell; and	Thermal runaway was achieved in all five cells by external heat applied by external heating Refer to attachment C and D.	F
	b) The cell vent gas does not present a flammability hazard when mixed with any volume of air, at both ambient and vent temperatures.	Cell vent gas found to be flammable. Refer to table 8.	F

UL 9540A, Edition 4,			
Clause	Requirement + Test	Result - Remark	Verdict

Table 1 – Specified conditioning parameters			
Charging:		Discharging	
Current (CC), A	47.3	Current (CC), A	47.3
Standard full charge voltage, Vdc	4.15	Voltage at start of discharge, Vdc	4.15
End of charge current, A	29	End of discharge voltage, Vdc	2.7
Charging Test Ambient, °C	0 to 60	Discharging Test Ambient, °C	0 to 60
Refer to Attachment A for charge/discharge profiles for each cell.			

Table 2 – Charge completion and cell test initiation times		
Cell Test Number	**Charge Completion Date and Time**	**Cell test Date and Time**
1	2023-02-21, 08:29:14	2023-02-21, 11:46:21
2	2023-02-21, 08:31:03	2023-02-21, 14:39:22
3	2023-02-21, 08:30:05	2023-02-21, 16:36:00
4	2023-02-22, 07:10:18	2023-02-22, 09:59:16
5	2023-03-28, 08:19:16	2023-03-28, 13:12:52

Table 3 - Test Initiation Details					
	Cell Test 1	**Cell Test 2**	**Cell Test 3**	**Cell Test 4**	**Cell Test 5**
Test Date	2023-02-21	2023-02-21	2023-02-21	2023-02-22	2023-03-28
Test Start Time	11:46:21	14:39:22	16:36:00	09:59:16	13:12:52
Initial Lab Temperature	20.6	20.0	20.4	21.5	21.3
Initial Relative Humidity	27.1	51.4	41.0	38.5	36.0

Table 4 - Thermal Runaway Results					
	Cell Test 1	**Cell Test 2**	**Cell Test 3**	**Cell Test 4**	**Cell Test 5**
OCV at start of test, Vdc	4.10	4.11	4.10	4.10	4.12
Average Heating Rate, °C/min	5.51	5.59	5.66	5.58	5.58
Venting Time after the test start (hh:mm:ss)	00:39:54	00:39:13	00:39:40	00:38:40	00:38:36
Venting Temperature, °C	163	163	166	168	164
Thermal Runaway Time after the test start (hh:mm:ss)	00:43:53	00:42:56	00:39:41	00:42:21	00:42:00
Thermal Runaway Temperature, °C	177	176	166	184	186
Refer to Attachment C for surface temperature profiles during testing See attachment E for datasheets Temperatures indicated above are taken from the thermocouple located on the side of the cell that is not covered by the heater.					

Table 5 – Average Vent and Thermal Runaway Temperatures	
Average of Cell Vent Temperatures, °C	166
Average of Cell Thermal Runaway Temperatures, °C	178
#Averages of cell tests other than the gas analysis test (Cell test 5)	

Table 6 – Parameters Flow Battery	
Single Electrolyte Flow Battery:	N/A
• Volume of Electrolyte Used for Flammability Determination, L	N/A
• Percentage of metal particles representative of fully charged electrolyte (% per volume of test electrolyte)	N/A
• Maximum volume of electrolyte for planned system, L	N/A
Two Electrolyte Flow Battery:	N/A
• Volume of Electrolyte No. 1 Used for Flammability Determination, L	N/A
• Volume of Electrolyte No. 2 Used for Flammability Determination, L	N/A
• Max. volume of electrolyte No. 1 in system, L	N/A
• Max. volume of electrolyte No. 2 in system, L	N/A
Two Electrolyte Flow Battery: Method for charging electrolytes to activate them	N/A
Electrolyte viscosity at 25°C (77°F), m^2/sec of Electrolyte 1	N/A
Electrolyte viscosity at 25°C (77°F), m^2/sec of Electrolyte 2	N/A
ASTM Method to Determine Flash Point:	N/A
Abnormal test methods used for single electrolyte flow battery:	N/A
Abnormal test methods used for two electrolyte flow battery:	N/A
Representative flow battery system used for abnormal testing:	N/A
• Manufacturer:	N/A
• Model No.:	N/A
• Electrical Ratings, Vdc, Ah	N/A
• Total Electrolyte No. 1 Contained, L	N/A
• Total Electrolyte No. 2 Contained, L	N/A

Table 7 – Results of Flammability Testing of Flow Battery Electrolyte	
Flash Point Determined:	N/A
Flash Point Temperature of electrolyte 1, °C:	N/A
Test temperature of electrolyte 1,° C:	N/A
Flash point temperature of electrolyte 2, °C:	N/A
Test temperature of electrolyte 2, °C:	N/A
Two electrolyte flow battery: Maximum temperature measured when mixing electrolytes, °C:	N/A
Maximum electrolyte temperature measured during abnormal testing, °C: • Short circuit test from UL1973:	N/A
• Overcharge test from UL 1973:	N/A

Table 8 – Results of Gas Analysis (Excluding O_2 and N_2)			
Gas		**Measured %**	**Component LFL[1]**
Hydrogen	**H2**	32.70 %	4.0 %
Carbon monoxide	**CO**	40.90 %	10.9 %
Carbon dioxide	**CO2**	9.20 %	--
Methane	**CH4**	15.43 %	4.4 %
Ethane	**C2H6**	1.06 %	2.4 %
Ethylene	**C2H4**	0.56 %	2.4 %
Propane	**C3H8**	0.03 %	1.7 %
Propene (Propylene)	**C3H6**	0.04 %	2.0 %
C4 Total[2]	**--**	0.05 %	--
C5 Total	**--**	0.01 %	--
Benzene	**C6H6**	0.06 %	1.2 %
Total	**--**	100 %	--

Table 9 – Gas composition excluding the constituents with boiling points higher than 60°C[3]			
Gas		**Measured %**	**Component LFL**
Hydrogen	**H2**	32.71	4.0
Carbon monoxide	**CO**	40.91	10.9
Carbon dioxide	**CO2**	9.20	--
Methane	**CH4**	15.43	4.4
Ethane	**C2H6**	1.06	2.4
Ethylene	**C2H4**	0.56	2.4
Propane	**C3H8**	0.03	1.7
Propene (Propylene)	**C3H6**	0.04	2.0
C4 Total[2]	**--**	0.05	--
C5 Total	**--**	0.01	--
Total	**--**	100.00	--

[1] Extracted LFL values from ISO 10156-2017

[2] Average of n-Butane, 1-Butene, cis-Butene, trans-Butene

[3] The constituents with a higher boiling point were excluded for the flammability characteristic analysis as these components will turn into a liquid state at room temperature and will not release from the gas bottle as a homogenous mixture.

Table 10 – Properties of Vent Gas Analysis	
Lower Flammability limit at Ambient Temperature, 25°C (% vol in air)	8.04
Lower Flammability limit at Vent Temperature, [166 °C] (% vol in air)	6.74
Flow Batteries, LFL scaled to maximum electrolyte volume of system, 25°C (% vol in air)	N/A
Flow Batteries, LFL scaled to maximum electrolyte volume of system, [°C] (% vol in air)	N/A
Burning Velocity Measurement, S_u cm/sec	86.40
Maximum Pressure P_{max}, psig	105.3

	TABLE: Critical components information				
Object / part No.	**Manufacturer/ trademark**	**Type / model**	**Technical data**	**Standard**	**Mark(s) of conformity**
Cell Model	SAMSUNG SDI CO LTD	CP1495L101+	3.68 Vdc, 145 Ah	UL 1973 , Appendix E UL 9540A	UL (MH64496) Tested within appliance
Cell case	--	--	Al, (0.6 ~ 1.2) mm	--	--
Electrolyte	--	--	LiPF6 salt, EC/EMC/DMC mixture	--	--
Separator	--	--	Ceramic / PE, Thickness: 16 µm	--	--
Insulation	--	--	PET, Thickness: 0.1 mm	--	--
Anode	--	--	Graphite	--	--
Cathode	--	--	NCA	--	--
Cu Foil (for Anode)	--	--	Cu, 8 µm	--	--
Al Foil (for Cathode)	--	--	Al, 12 µm	--	--
Vent or pressure release mechanism	--	--	Notch Type	--	--

~~**List of test equipment used:**~~

~~A completed list of used test equipment shall be provided in the Test Reports when a Customer's Testing Facility has been used.~~

Clause	Measurement / testing	Testing / measuring equipment / material used, (Equipment ID)	Range used	Last Calibration date	Calibration due date

Attachment A: Cell Conditioning (Charge/discharge) Profiles - (*Pages **16** through **20***)

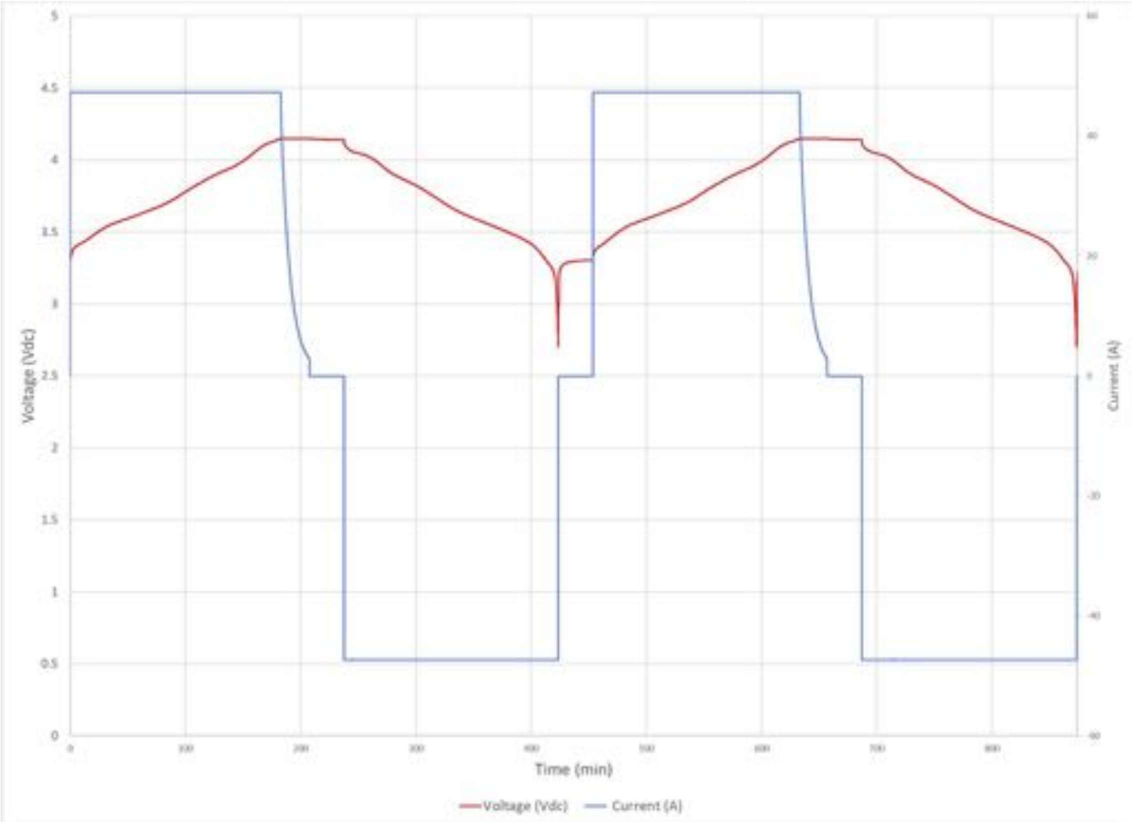


Figure A1: Sample 1 - Cell Conditioning Profile

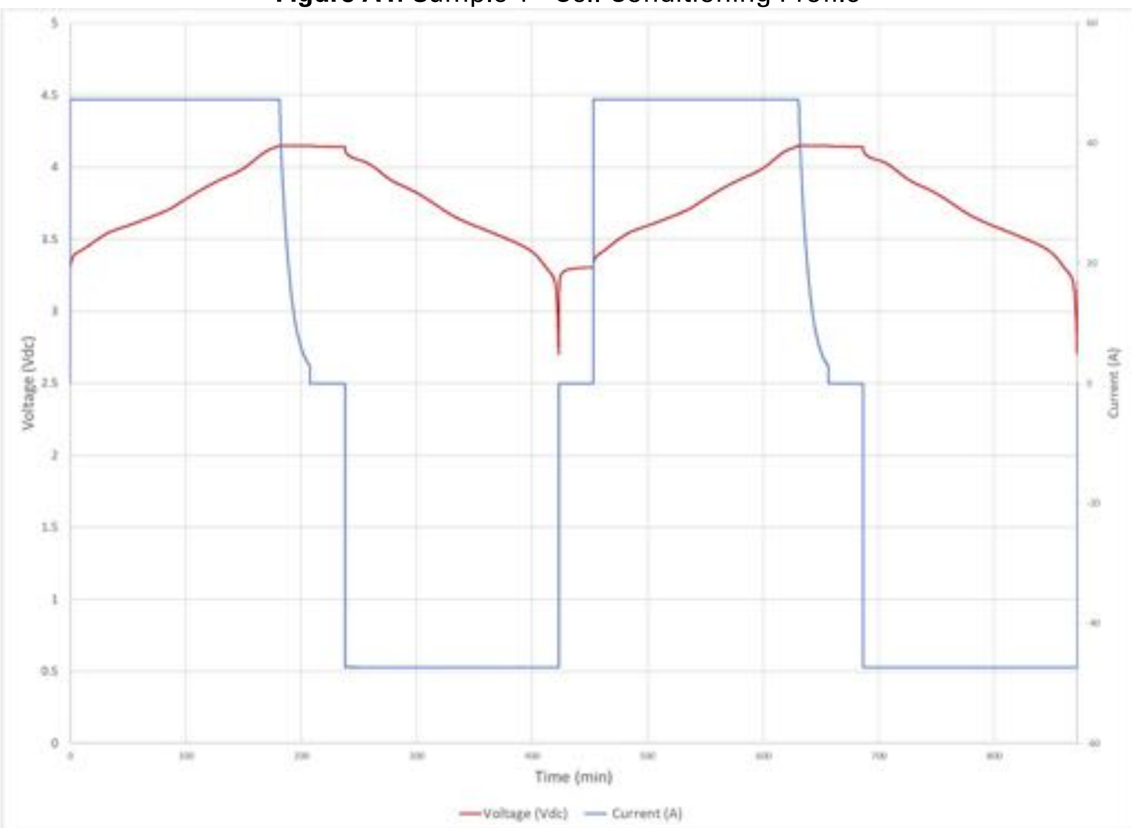


Figure A2: Sample 2 - Cell Conditioning Profile

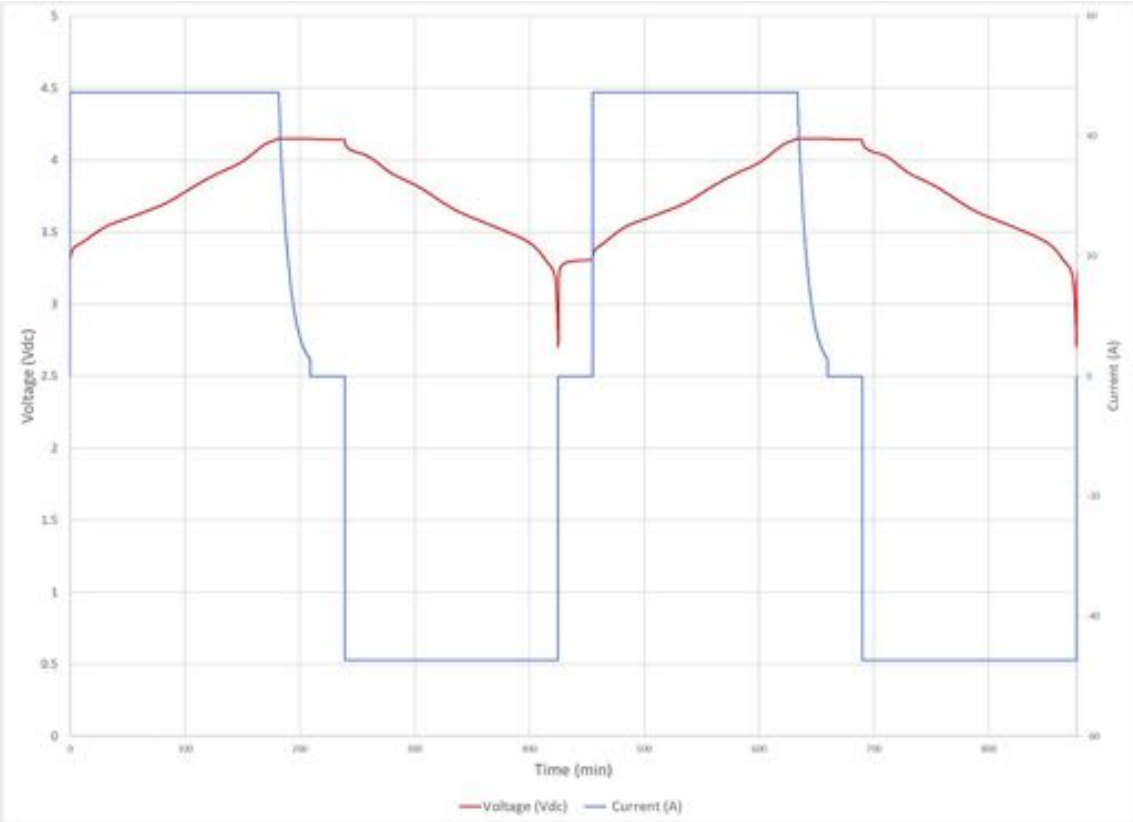


Figure A3: Sample 3 - Cell Conditioning Profile

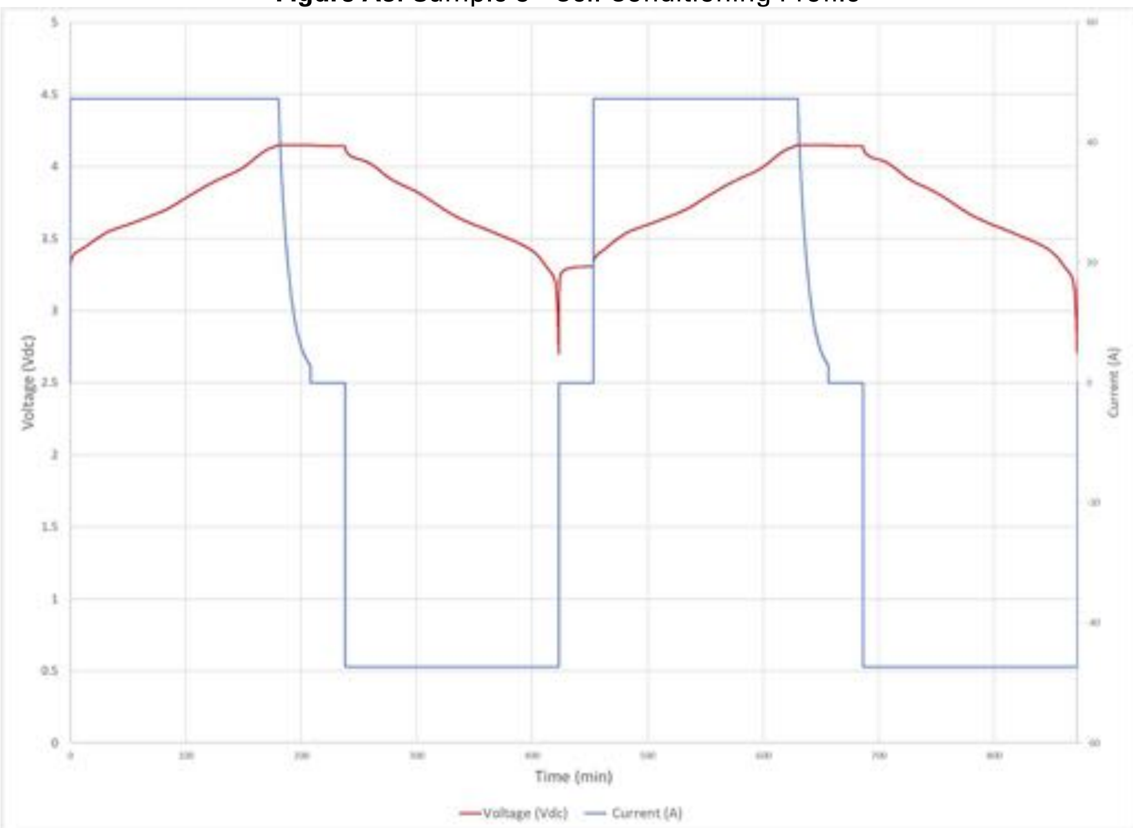


Figure A4: Sample 4 - Cell Conditioning Profile

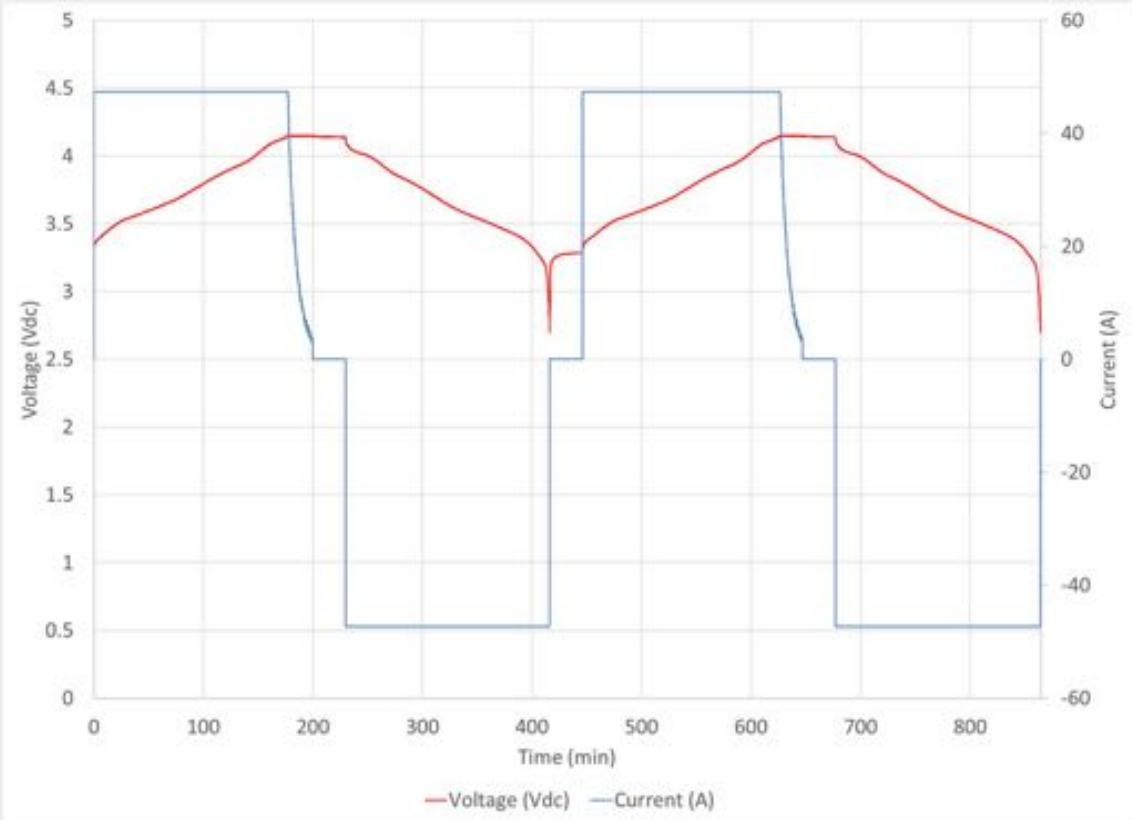


Figure A5: Sample 5 - Cell Conditioning Profile

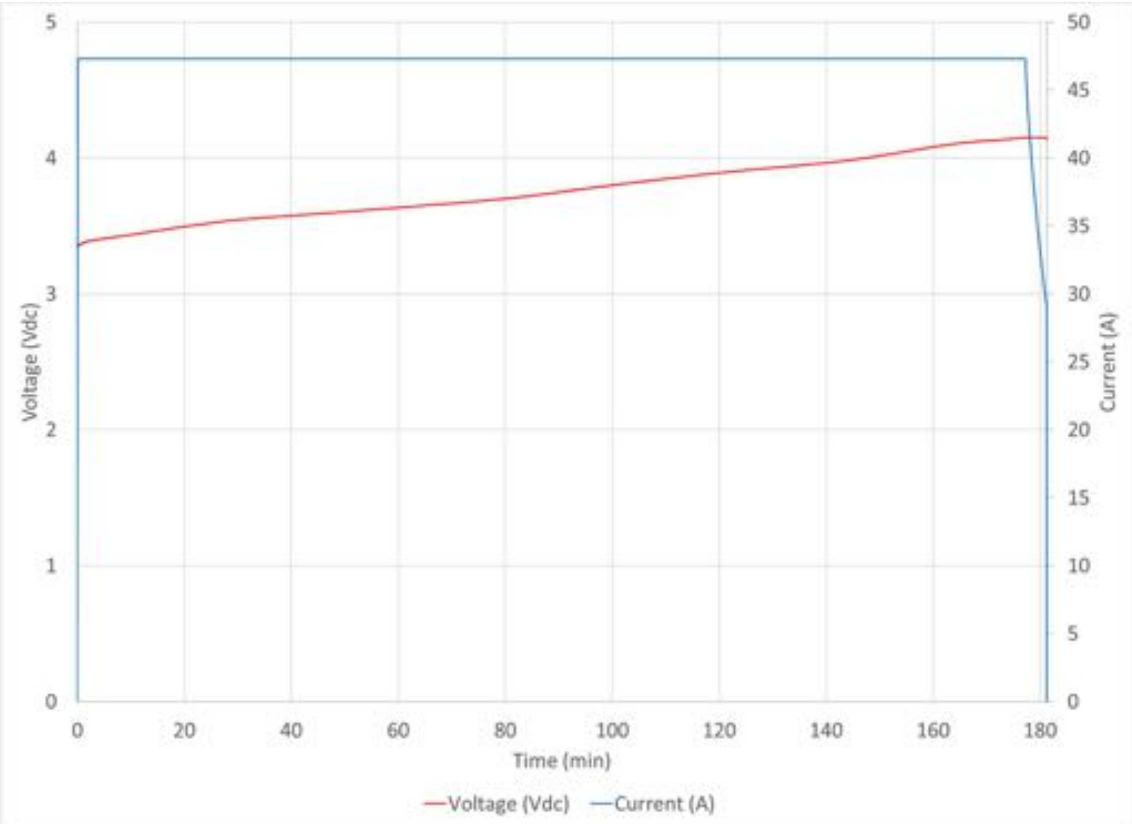


Figure A6: Sample 1 Charging and Top-off Profile

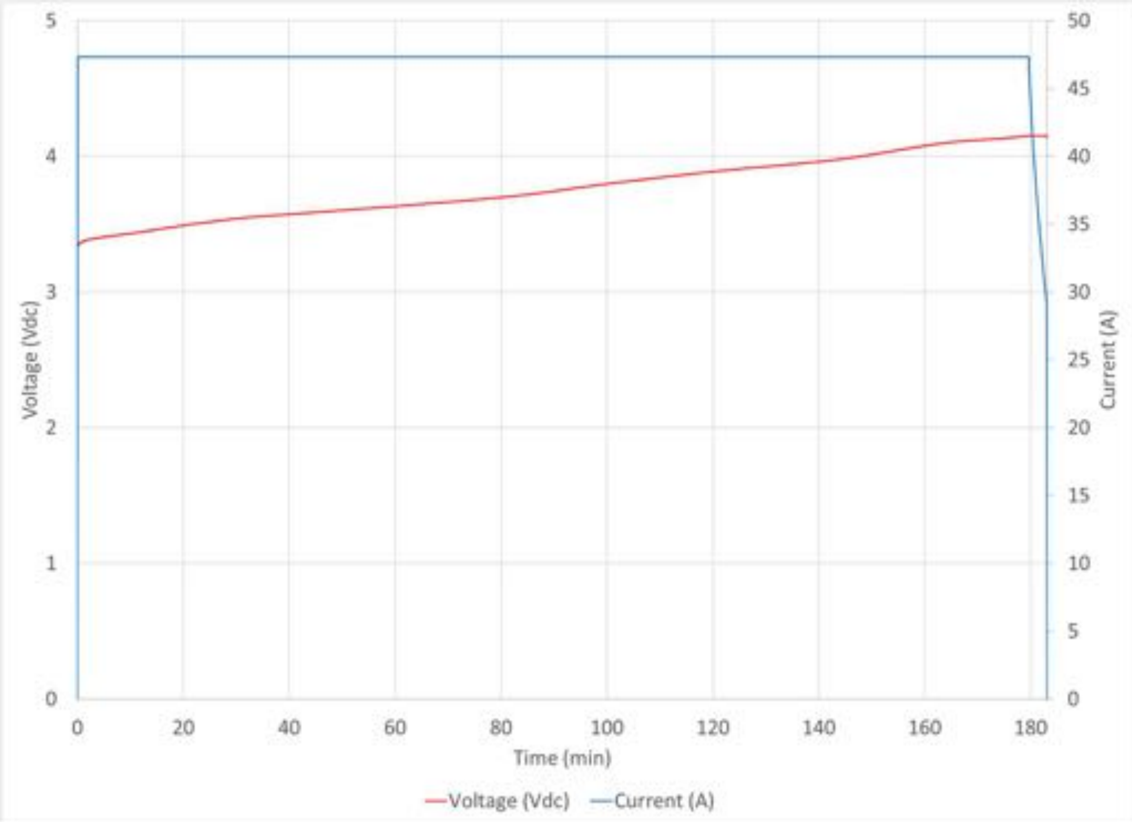


Figure A7: Sample 2 Charging and Top-off Profile

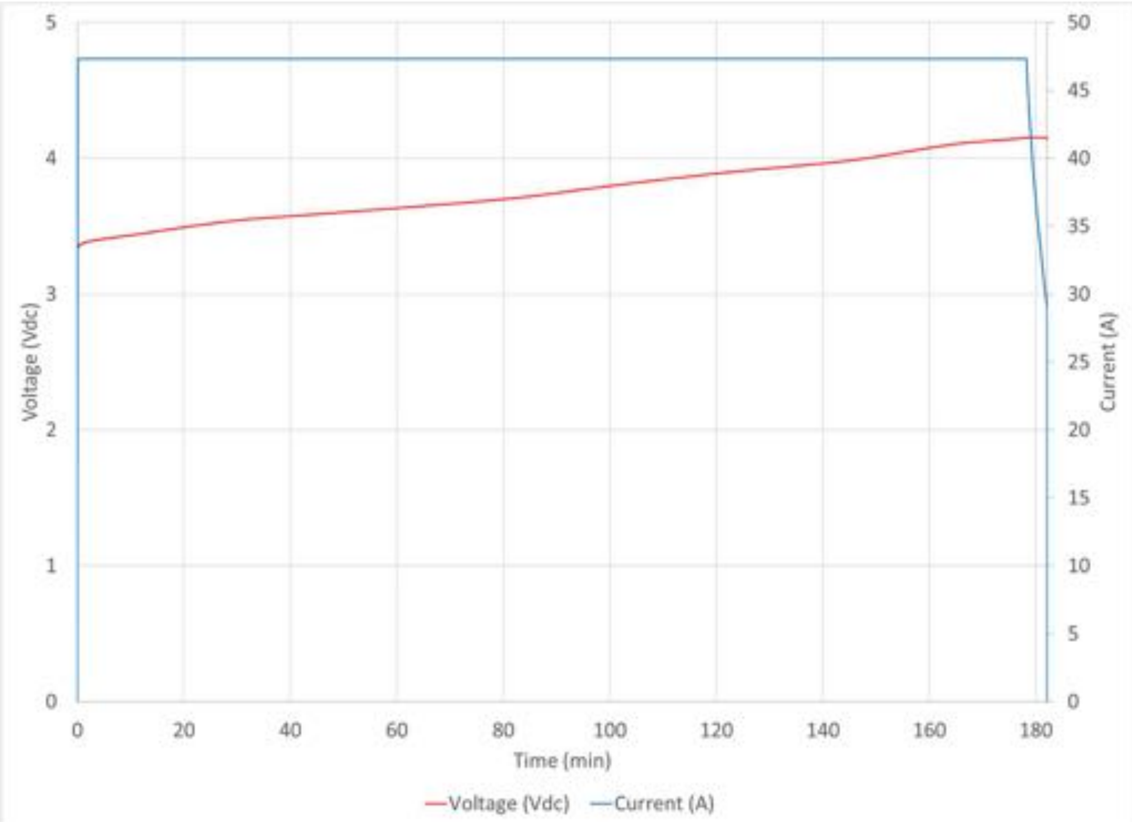


Figure A8: Sample 3 Charging and Top-off Profile

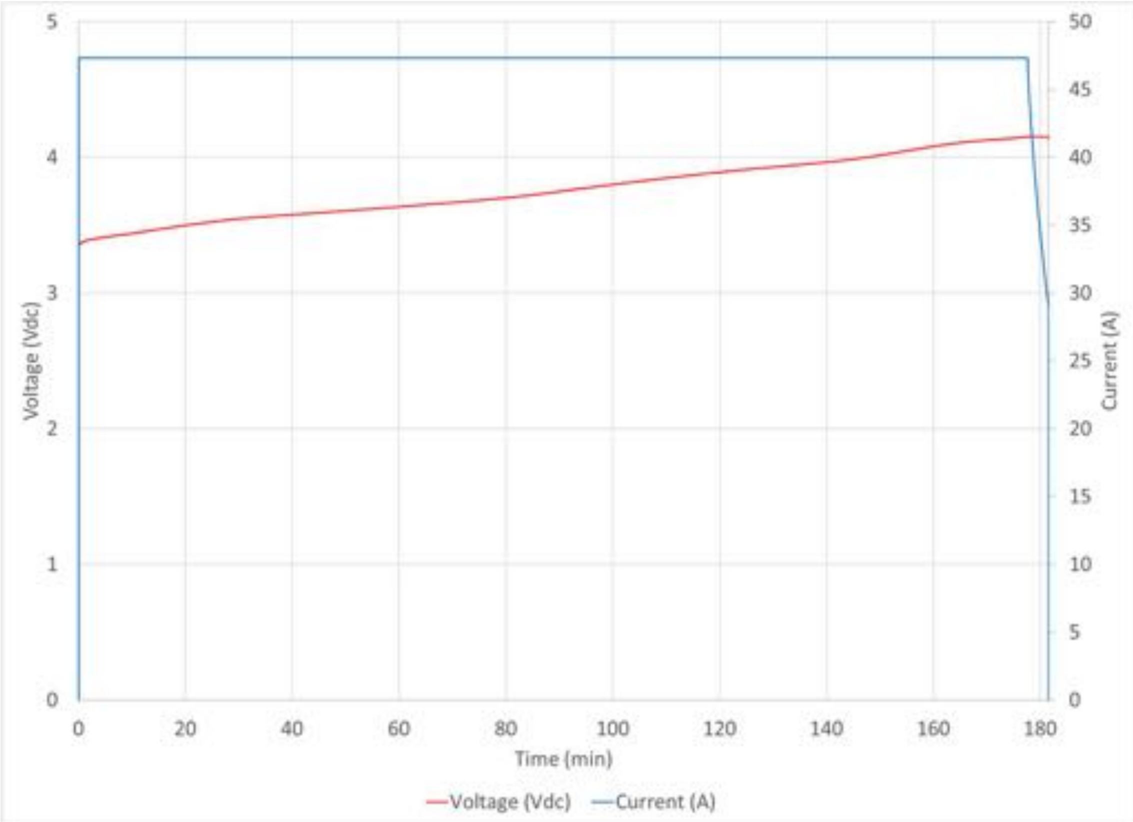


Figure A9: Sample 4 Charging and Top-off Profile

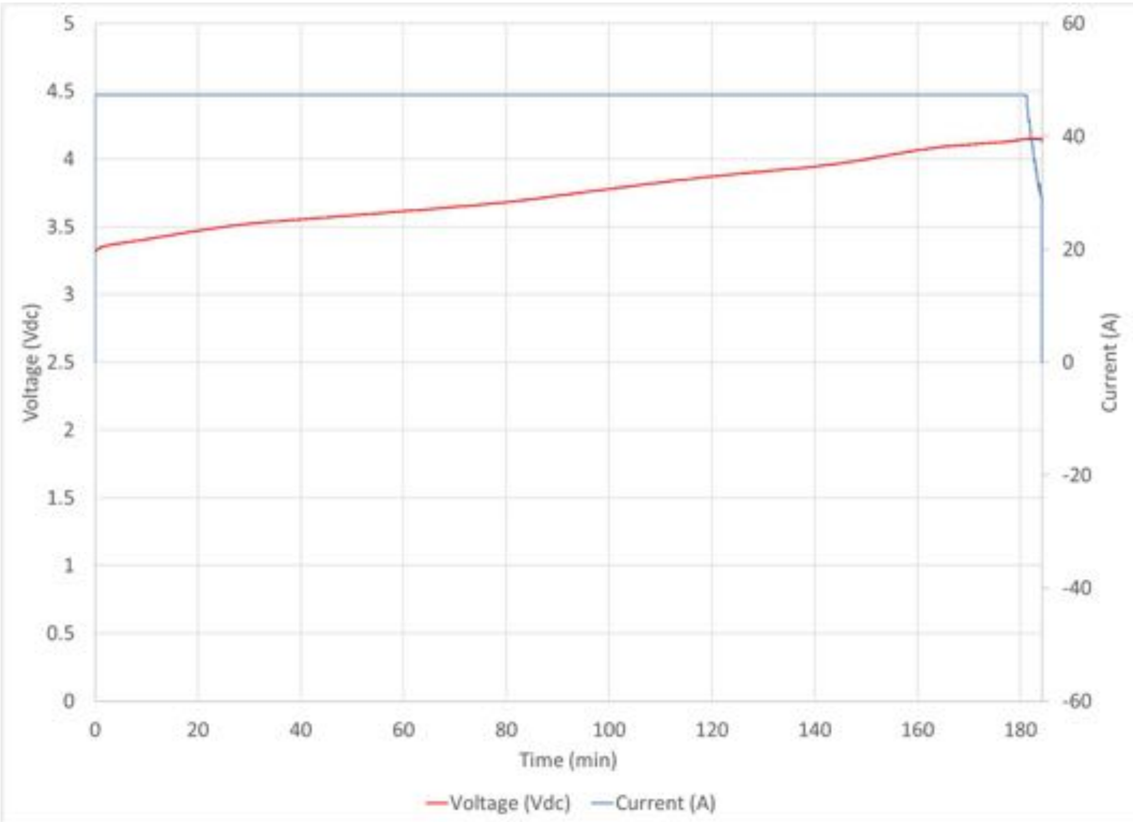
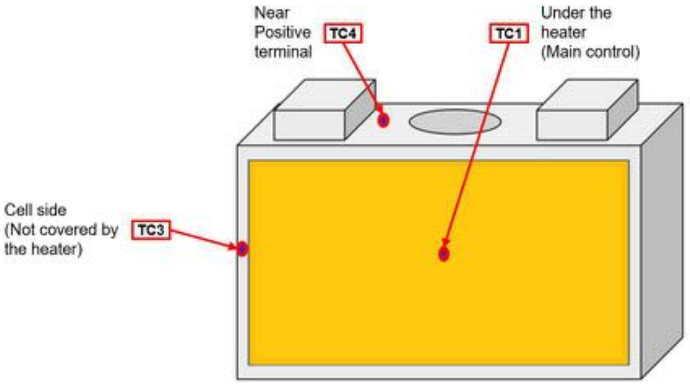


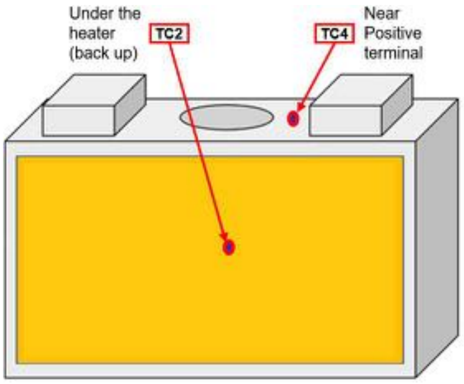
Figure A10: Sample 5 Charging and Top-off Profile

Attachment B: Cell Instrumentation Photos - (*Pages **21** through **22***)

Initiating Cell (Normal Thermal Runaway and Gas Chamber)

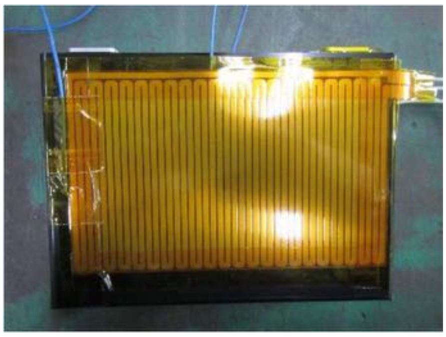
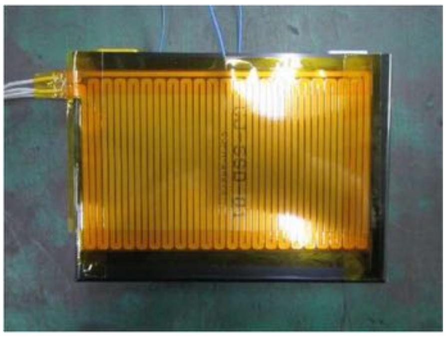
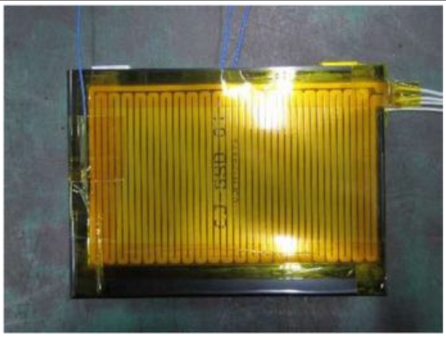
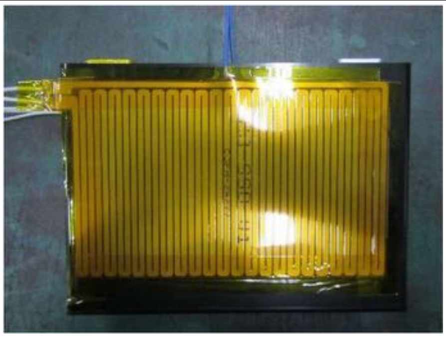
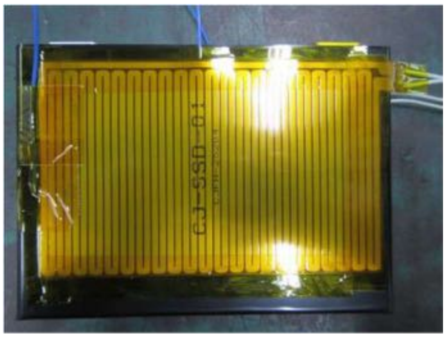
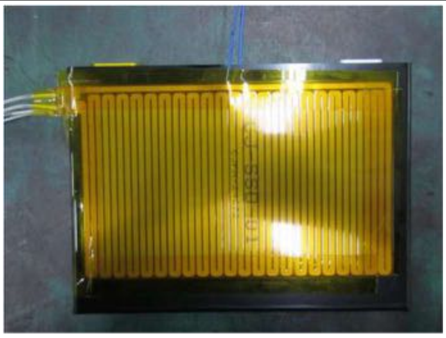
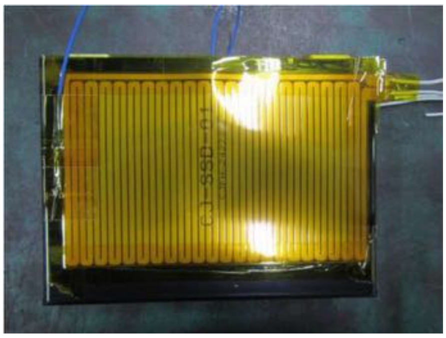
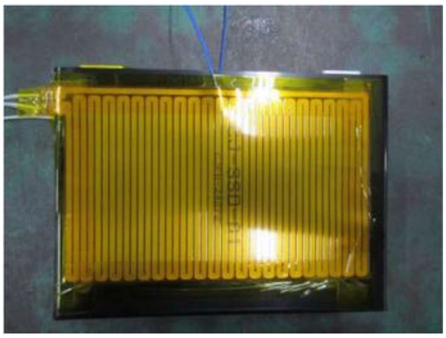
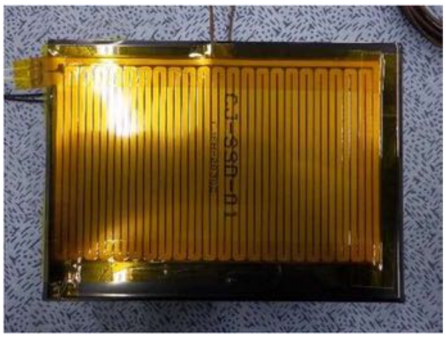


<Front>



<Back>

TC No.	Descriptions
TC1	Under the heater (Main control)
TC2	Under the heater (back up)
TC3	Cell side
TC4	Near Positive terminal

Front	Back	
		**Figure B1:** Sample No. 1
		**Figure B2:** Sample No. 2
		**Figure B3:** Sample No. 3
		**Figure B4:** Sample No. 4
		**Figure B5:** Sample No. 5

Attachment C: Cell Temperature Profiles during testing - (*Pages **23** through **25***)

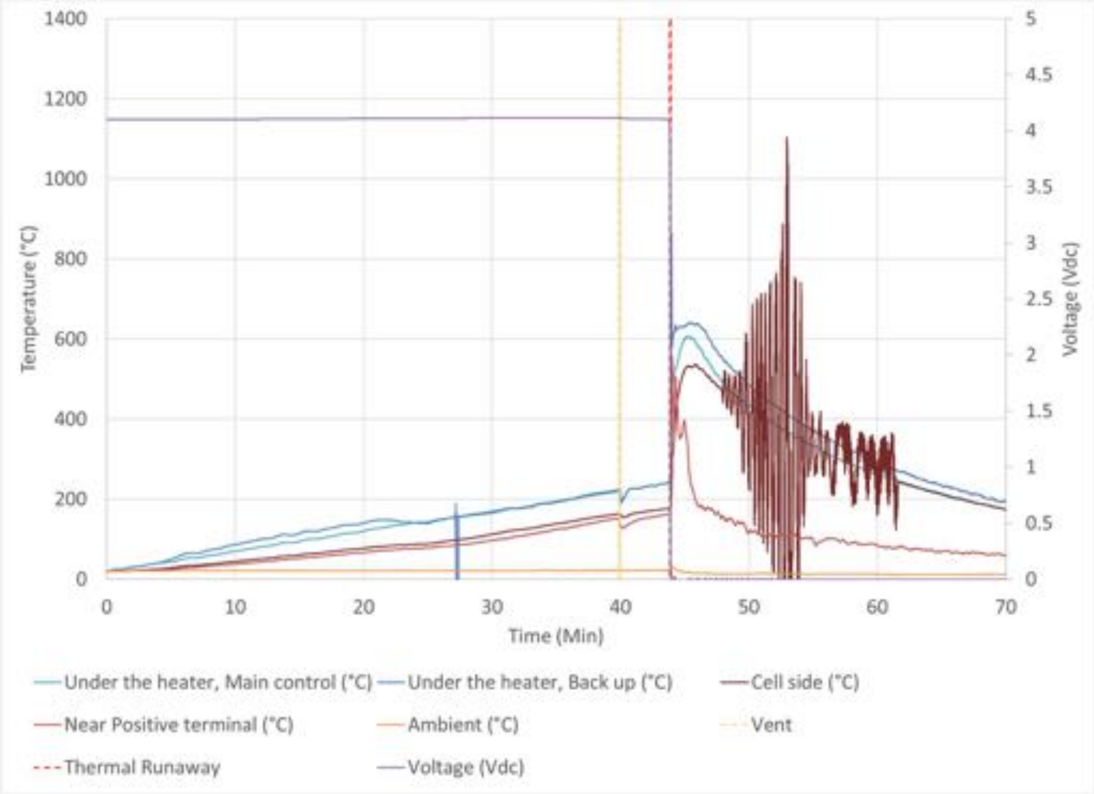


Figure C1: Sample 1 - Thermal Runaway & Vent Temperature

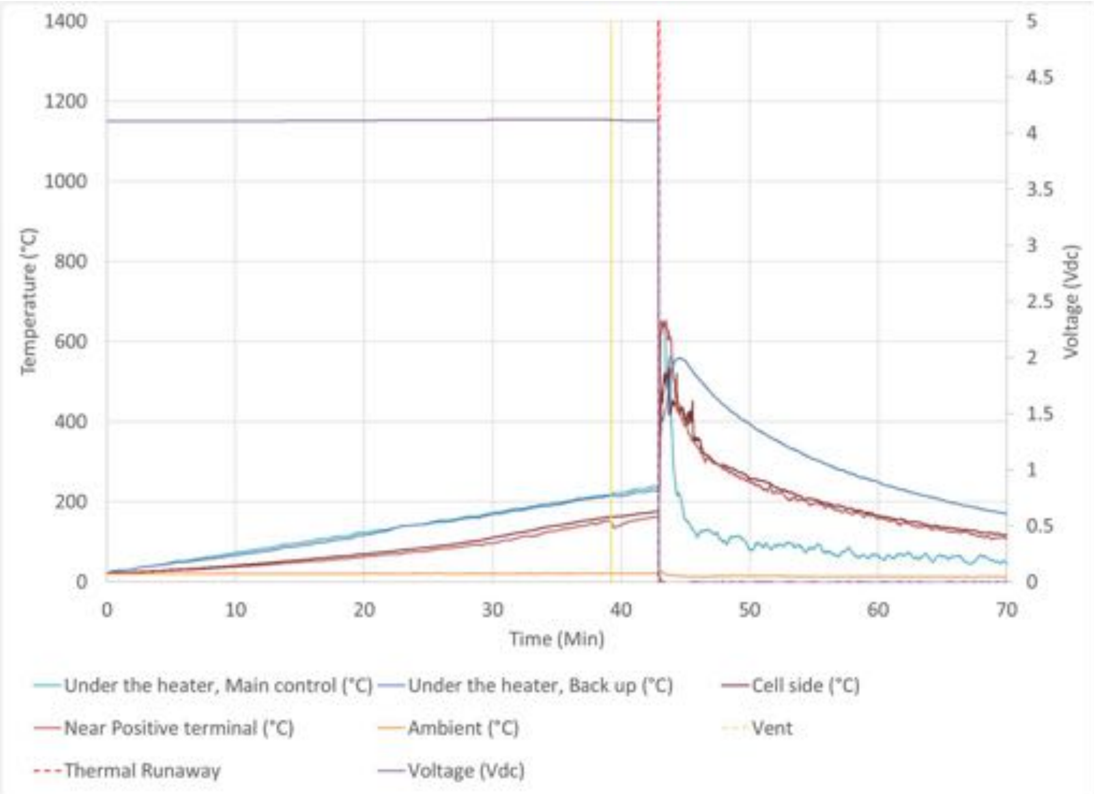


Figure C2: Sample 2 - Thermal Runaway & Vent Temperature

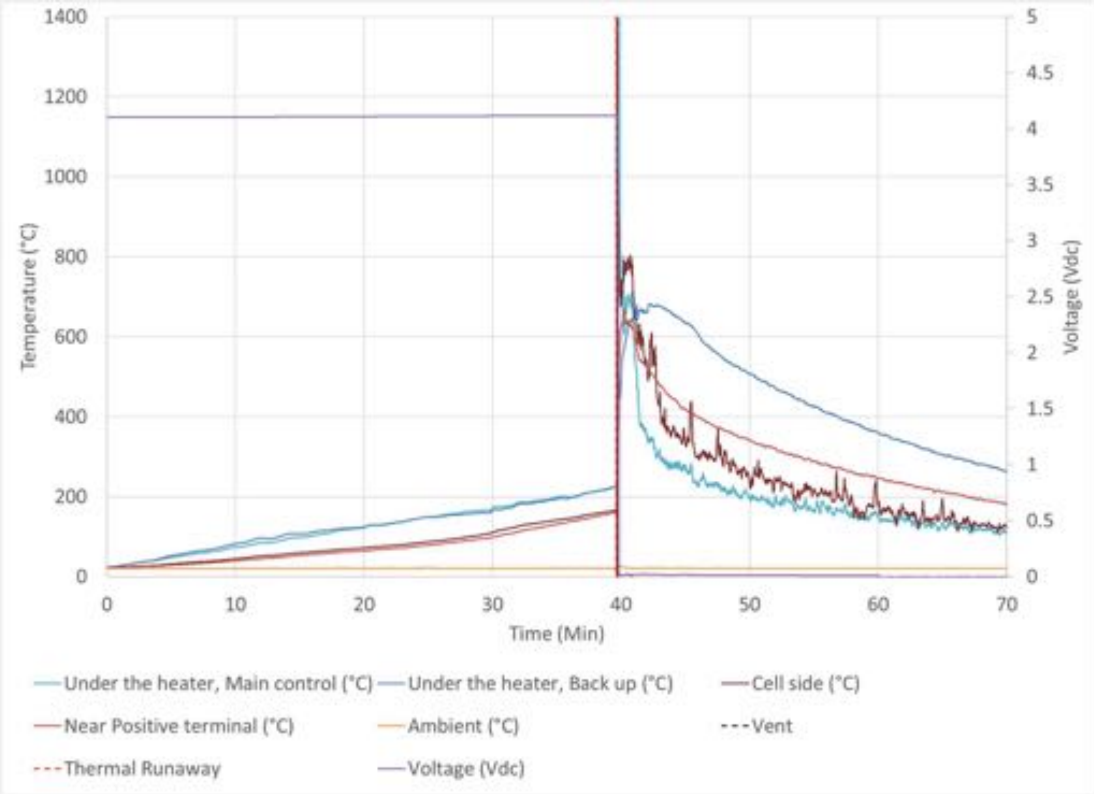


Figure C3: Sample 3 - Thermal Runaway & Vent Temperature

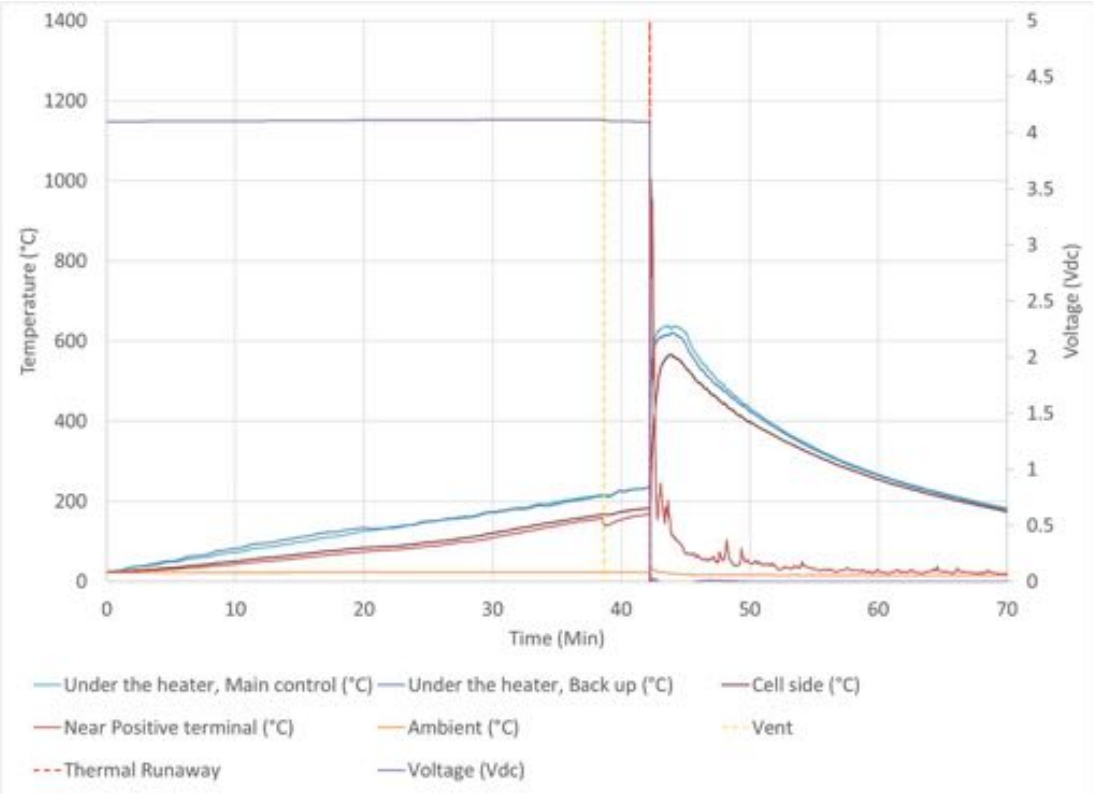


Figure C4: Sample 4 - Thermal Runaway & Vent Temperature

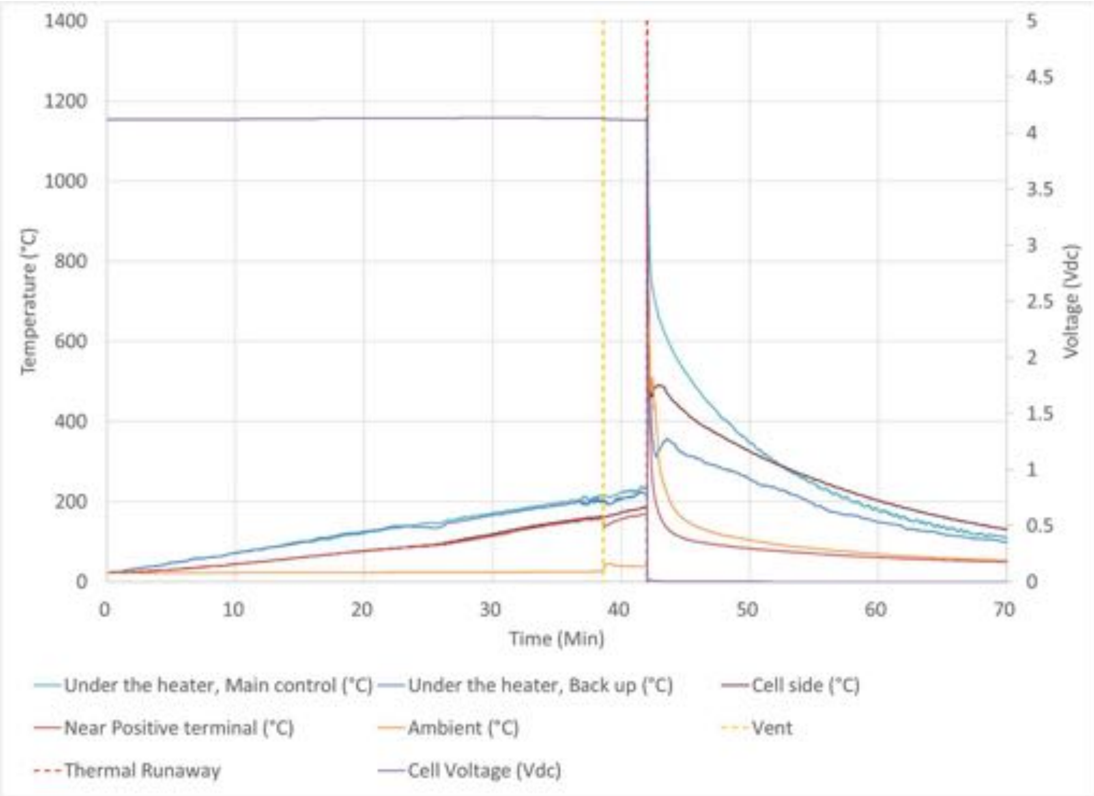
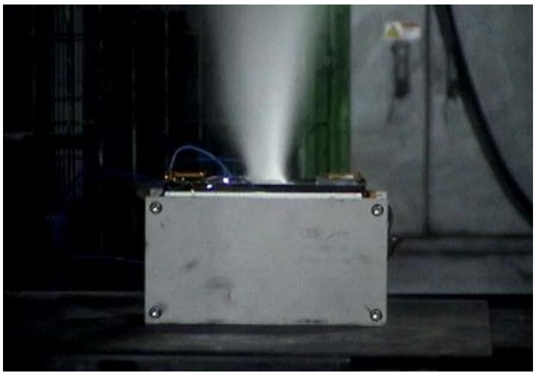
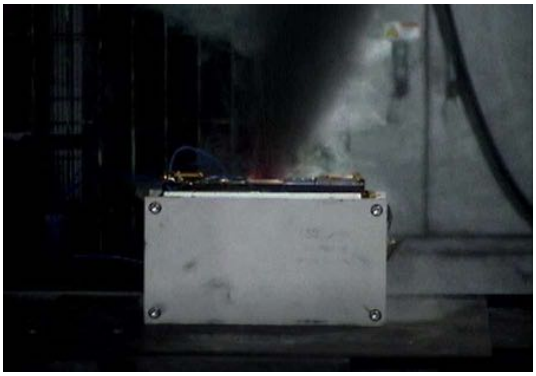
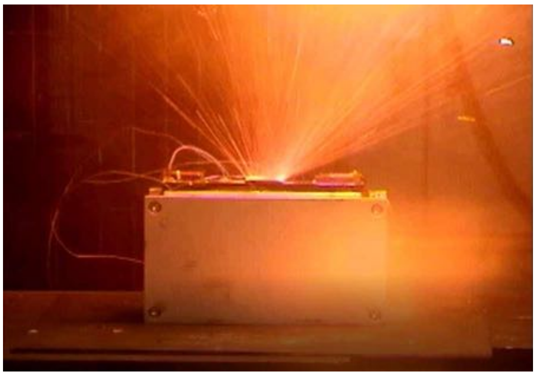


Figure C5: Sample 5 - Thermal Runaway & Vent Temperature

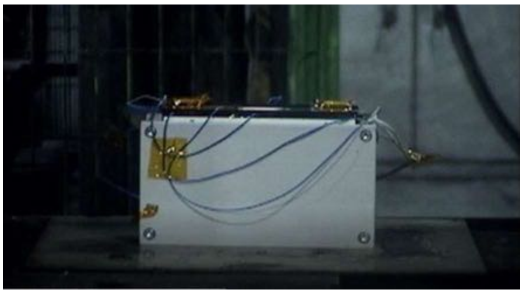
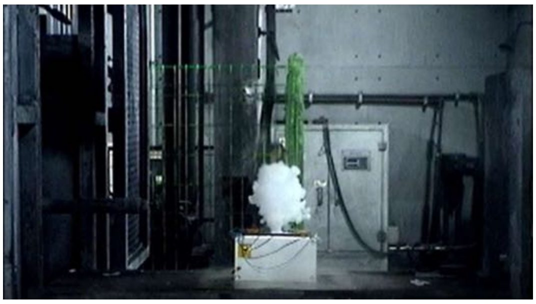
Attachment D: Cell Testing Photos - (*Pages **26** through **30***)

Cell Test 1

<table>
<tr><td></td><td></td></tr>
<tr><td>Cell 1 - Start of test (00:00:00)</td><td>Cell 1 - Venting (00:39:54)</td></tr>
<tr><td></td><td></td></tr>
<tr><td>Cell 1 - Immediately before thermal runaway* (00:43:54)</td><td>Cell 1 - Thermal runaway (00:43:55)</td></tr>
<tr><td colspan="2"></td></tr>
<tr><td colspan="2">Cell 1 - After the end of test</td></tr>
</table>

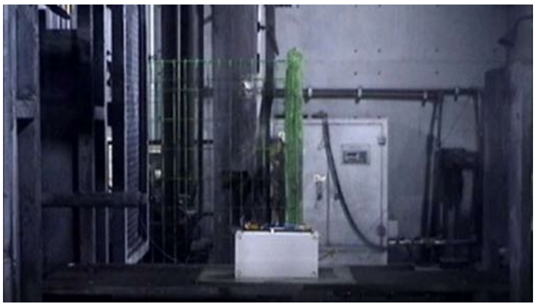
*Note: Thermal runaway was determined when the temperature of the cell surface increased in an uncontrollable manner.

Cell Test 2

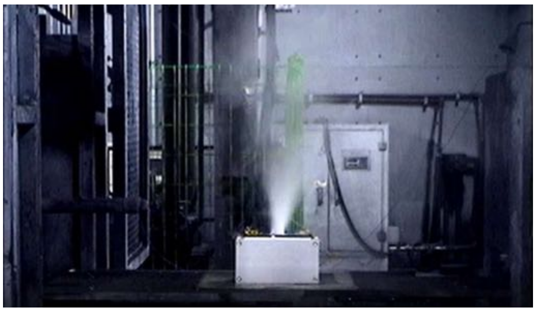
	
Cell 2 - Start of test (00:00:00)	Cell 2 - Venting (00:39:13)
	
Cell 2 - Immediately before thermal runaway* (00:42:57)	Cell 2 - Thermal runaway (00:42:58)
	
Cell 2 - After the end of test	

*Note: Thermal runaway was determined when the temperature of the cell surface increased in an uncontrollable manner.

Cell Test 3



Cell 3 - Start of test (00:00:00)



Cell 3 - Venting (00:39:42)

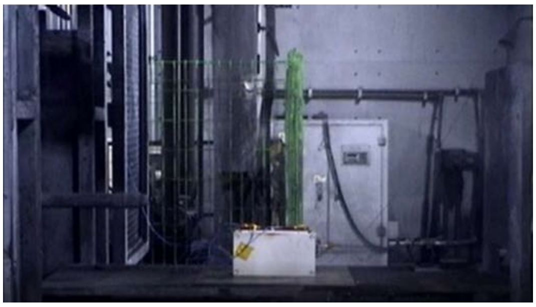
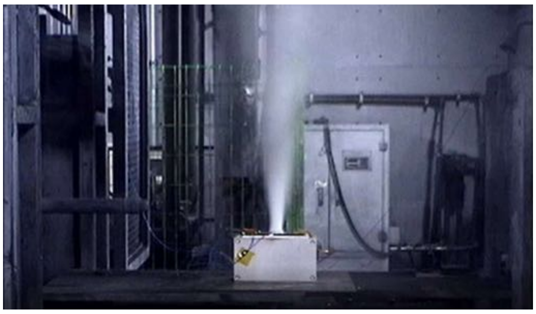
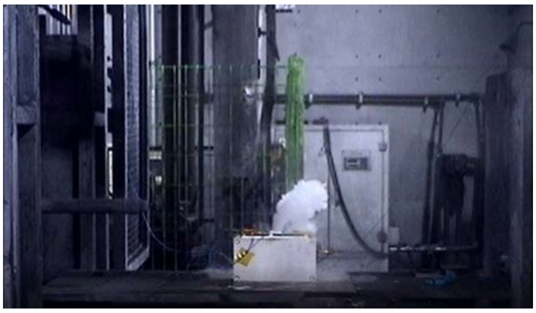
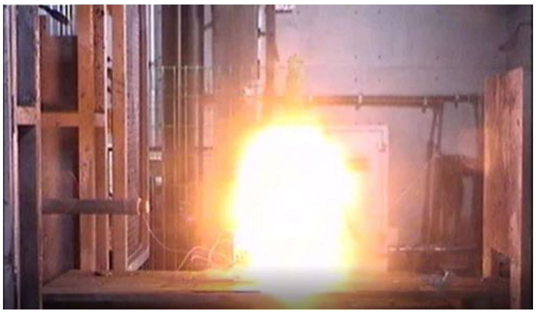
Cell 3 - Immediately before thermal runaway* (00:39:42)

Cell 3 - Thermal runaway (00:39:43)

Cell 3 - After the end of test

*Note: Thermal runaway was determined when the temperature of the cell surface increased in an uncontrollable manner.

Cell Test 4

	
Cell 4 - Start of test (00:00:00)	Cell 4 - Venting (00:38:40)
	
Cell 4 - Immediately before thermal runaway* (00:42:16)	Cell 4 - Thermal runaway (00:42:17)
	
Cell 4 - After the end of test	

*Note: Thermal runaway was determined when the temperature of the cell surface increased in an uncontrollable manner.

Cell Test 5

Video was not recorded because this cell was placed inside the gas collection vessel

Attachment E: Cell Test Datasheets - (*Pages **31** through **31***)

Cell Test Datasheet is stored in the UL database

Attachment F: Cell vent gas test chamber photo and profile of chamber gas analysis (O_2 and Pressure) - (*Pages **32** through **33***)

This Attachment depicts the equipment used to capture the vented gases.

<Vessel>

Figure F1: Gas Collection Chamber Test Set-up

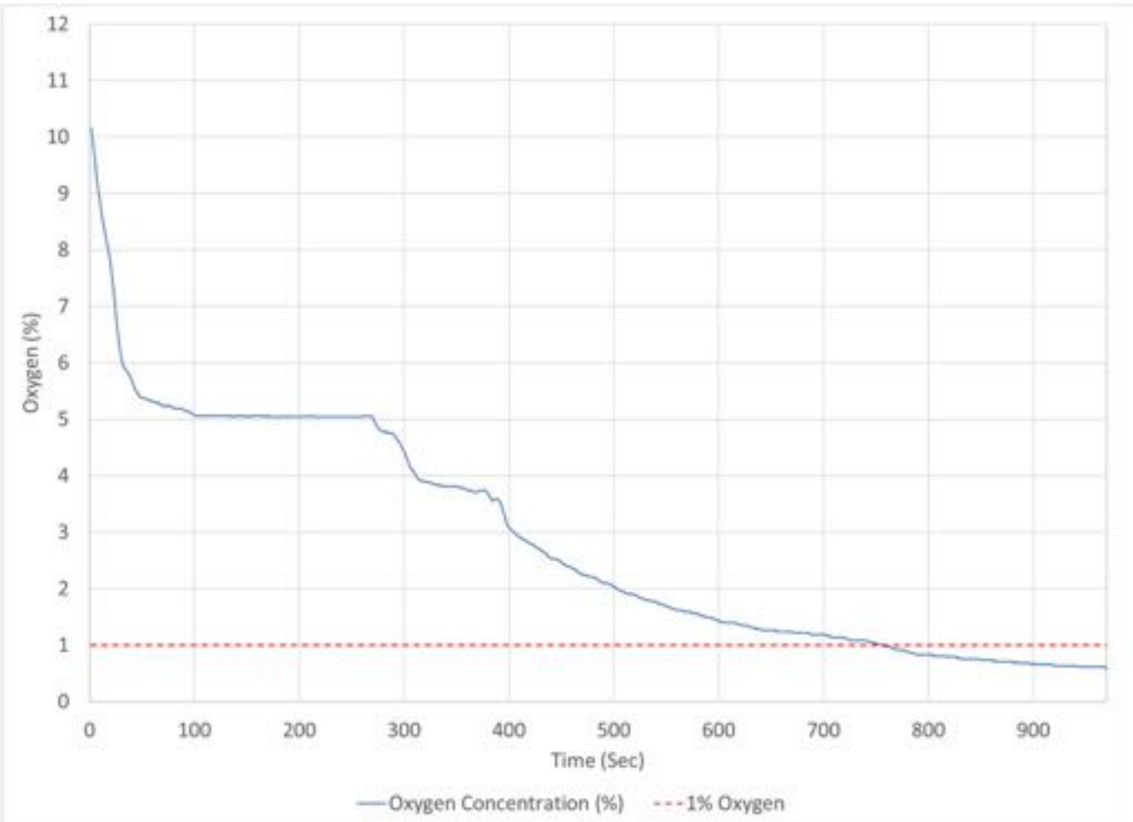


Figure F2: Gas Collection Chamber – Concentration Profile during Oxygen Purge

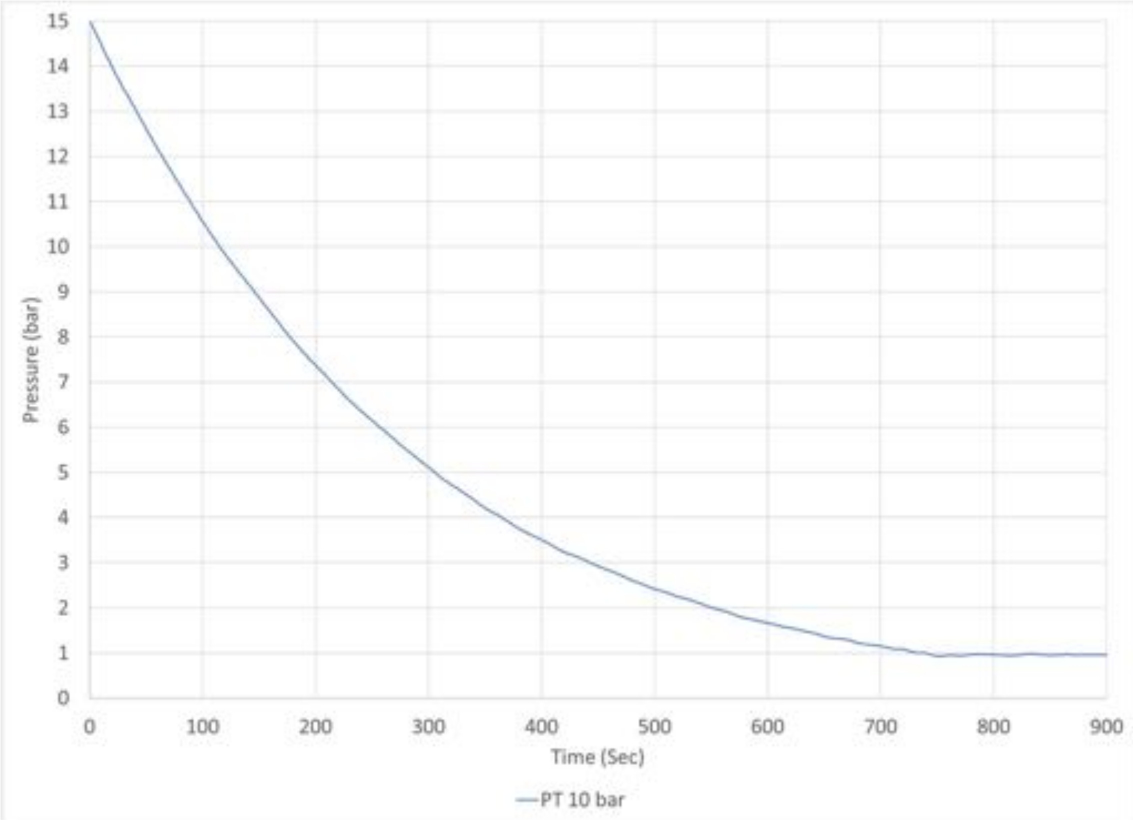


Figure F3: Gas Collection Chamber – Pressure Profile prior to Gas Collection Test

Attachment G: Certification Requirement decisions (*Pages* **34** *through* **34**)

UNDERWRITERS LABORATORIES INC. CERTIFICATION REQUIREMENT DECISION

This Certification Requirement Decision is prepared by UL LLC. It is normative for the applicable UL Product Certification Program(s); however, it is currently not part of the UL Standard(s) referenced below.

Product Category (CCN): AACD
Standard Number: UL 9540A
Standard Title: Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems
Edition Date: November 12, 2019
Edition Number: 4
Section / Paragraph Reference: 7.3.1.5
Subject: Option to do a continuous thermal ramp until thermal runaway

DECISION:

7.3.1.5 Before beginning the test, a surface temperature shall be determined to approximate the temperature at which internal short circuiting within the cell will occur that could lead to a thermal runaway condition. For Li-ion cells, the surface temperature hold point shall be between 5°C (9°F) and 15°C (27°F) greater than the melting temperature of the cell separator material as determined from differential scanning calorimetry (DSC) data of the separator in accordance with UL 2591 (UL 746A). Thermal runaway may occur before this hold point temperature range is reached. However, if thermal runaway is not achieved at this hold point temperature after a period of 4 h, the cell heating rate according to 7.3.1.2 shall be reestablished until thermal runaway occurs or it is demonstrated that thermal runaway is not achievable by heating.

Exception: If the separator information is not available or at the manufacturer's discretion, the thermal ramp can be conducted continuously without a hold point until thermal runaway.

RATIONALE FOR DECISION:

The cell failure method had always been a thermal ramp until thermal runaway occurred. The hold temperature was established because of concern that if the thermal ramp continued at too high of a temperature, it may melt the cell casing. However, the separator information may not always be available and it may be just easier to conduct the test with a continuous thermal ramp if the client is in agreement. In either case, the goal is to establish a thermal runaway condition.

<Certification Requirement Decision dated on 2020-05-20>

MODULE TEST REPORT
UL 9540A
Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems (AACD)

Project Number. ....:	**4790351859**
Date of issue..................................:	**2023-07-10**
Total number of pages ....:	**35**
UL Report Office ....:	**UL Solutions**
Applicant's name ....:	**Samsung SDI**
Address..:	**428-5 GONGSE-DONG GIHEUNG-GU YONGIN-SI, GYEONGGI-DO, 446-577 KR**
Test specification:	4th Edition, Section 8, November 12, 2019
Standard..:	UL 9540A, Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems
Test procedure ....:	8.1 – 8.4
Non-standard test method ....:	N/A

General disclaimer:

The test results presented in this report relate only to the sample tested in the test configuration noted on the list of the attachments.

UL LLC did not select the sample(s), determine whether the sample(s) was representative of production samples, witness the production of the test sample(s), nor were we provided with information relative to the formulation or identification of component materials used in the test sample(s).

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UL LLC, its employees, and its agents shall not be responsible to anyone for the use or non-use of the information contained in this Report, and shall not incur any obligation or liability for damages, including consequential damages, arising out of or in connection with the use of, or inability to use, the information contained in this Report.

Cell level information	
Cells in Module:	
●**Manufacturer Name**	Samsung SDI
●**Part Number**	CP1495L101A
●**Chemistry**	Lithium Nickel Aluminium Cobalt Oxide (LiNiAlCoO2)
●**Format**	Prismatic
Ratings (Vdc, Ah) :	3.68 V , 145Ah
Was the cell certified? :	Yes
Standard the cell was certified to:	UL 1973 (File Number: MH64496)
Organization that certified the cell:	UL Solutions
Average cell surface temperature at gas venting, °C:	166
Average cell surface temperature at thermal runaway, °C:	178
Gas Volume:	423
Lower flammability limit (LFL), % volume in air at the ambient temperature:	8.04
Lower flammability limit (LFL), % volume in air at the venting temperature:	6.74
Burning velocity (S_u) cm/s:	88.40
Maximum pressure (P_{max}) psig:	105.3

Cell Gas Composition:

Gas		Measured %
Hydrogen	H2	32.7
Carbon monoxide	CO	40.9
Methane	CH4	15.43
Ethylene	C2H4	0.56
Ethane	C2H6	1.06
Carbon dioxide	CO2	9.2
Propene (Propylene)	C3H6	0.04
Propane	C3H8	0.03
C4 Total	C4H?	0.05
C5 Total	C5H?	0.01
Benzene	C6H6	0.06
Total	-	100.00

Module Level Information	
Model No:	E5S (MS3204L101A)
Ratings (Vdc, Ah) :	110.4, 290
Module cell configuration (xS/**y**P) **……:**	30S/2P
Module dimensions (W x **D** x **H** (mm)) **:**	388.2 x 1751.8 x 155.0 (without mounting bracket)
Module weight (kgs) :	173
Module enclosure material:	Plastic Cover : PC(M3020PN), 2.5T Mica Sheet 0.3t(&Aerogel) Sheet
Was the module certified? :	Yes (MH49407)
Standard the module was certified to:	UL 1973
Organization that certified test item:	UL Solutions

Cell failure test method performed for the module level (summary of method and test clause):

☒ External heating using thin film with 4°C to 7°C thermal ramp.
☐ Nail Penetration ☐ Overcharge
☐ External short circuit (***X*** Ω *external resistance*)
☐ Others

Description of method used to fail cells if other than external thin film heater with thermal ramp, :
N/A

Description of components employed within the module that serve to supress propagation (fire protection features).

Number of initiating cells failed to achieve propagation.	1
Thermal Runaway Propagation:	Yes
Maximum Smoke Release Rate (m^2/s)	7.06
Total Smoke Released: (m^2)	3516
Total smoke released duration (hh:mm:ss)	04:44:13
Peak Chemical Heat Release Rate: (kW):	3935
External Flaming:	Yes
Location(s) of Flame Venting:	Flaming out of the top of the module
Flying Debris:	Yes

	Re-ignitions:	No re-ignition

Summary of Module level test Gas Analysis Data:

Gas Analysis:

☒ **Flame ionization detection**

☐ **Fourier-Transform infrared Spectrometer**

☒ **Hydrogen Sensor (palladium-nickel, thin-film solid state sensor)**

☒ **White light source with photo detector (smoke release rate)**

- **Gas Composition & Volume for Each Compound (Pre-flaming and After flame):**

Gas Compound	Gas Type	Pre-Flaming (L)	Flaming (L)	Minimum detectable flow rate(LPM)
Total Hydrocarbons (Propane Equivalent)	Hydrocarbons	6.61	677.14	0.04
Carbon Dioxide	Carbon Containing	Below detectable limit	39542.50	3.11
Carbon Monoxide	Carbon Containing	Below detectable limit	1421.12	0.44
Hydrogen	Hydrogen	*	*	*

*The hydrogen measurement system malfunctioned during the test, however, the same module design was tested with different charging specifications and the hydrogen quantity was below detectable limits – Please refer to the report under UL project 4790648531

Summary of Module testing:

Performance Criteria in accordance with Clause 8.4 and Figure 1.1:

[X] The effects of thermal runaway was not contained by the module design;

[X] Cell vent gas (based upon the cell level test) was flammable

Necessity of a unit level test

[X] The performance criteria of the module level test as indicated in 8.4 and as shown in Figure 1.1 of UL 9540A 4th edition has not been met, therefore unit level testing in accordance with UL 9540A will need to be conducted on a complete unit employing this module.

[ ] The performance criteria of the module level test as indicated in 8.4 and as shown in Figure 1.1 of UL 9540A 4th edition has been met, therefore unit level testing in accordance with UL 9540A need not be conducted.

Testing Laboratory information

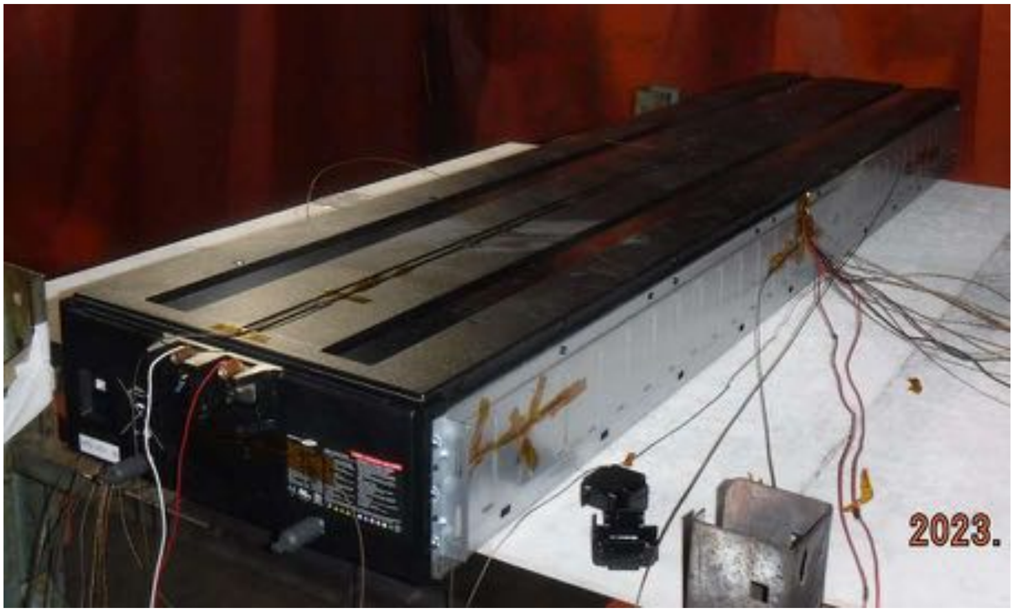
Testing Laboratory and testing location(s):

Testing Laboratory:	UL Solutions
Testing location/ address ....:	333 Pfingsten Rd. Northbrook, IL 60062 USA
Tested by (name, signature) ....:	Miguel Berumen

Witnessed by (for 3rd Party Lab Test Location) (name, signature) ....:	N/A	N/A
Project Handler (name, signature):	Daniel Wade	Daniel Wade
Reviewer (name, signature) …………….:	Sean Yang	

List of Attachments (including a total number of pages in each attachment):
Attachment A: Module Conditioning (Charge/discharge) Profiles - (*Pages **19** through **20***) **Attachment B:** Module Construction Photos - (Pages ***21*** through ***22***) **Attachment C:** Module Instrumentation Photos - (*Pages **23** through **24***) **Attachment D**: Module and Initiating Cell(s) Temperature Profiles During Testing - (*Pages **25** through **26***) **Attachment E**: Module Testing Photos - (*Pages **27** through **29***) **Attachment F**: Module Test Datasheets - (*Pages **30** through **30***) **Attachment G**: Module Gas Flow Rate and Heat Release Profiles - (*Pages **31** through **32***) **Attachment H**: Certification Requirement Decision - (*Pages **33** through **35***)

Photo(s) of module:



Test Item Charge/Discharge Specifications:	
• Charge current, A:	58.0
• Standard Full charge Voltage, Vdc:	124.5
• Charge temperature range, °C:	23 ± 5
• End of charge current, A:	58.0
• Discharge current, A:	58.0
• End of discharge voltage, Vdc:	93.0
• Discharge temperature range, °C:	23 ± 5

UL 9540A, Edition 4,			
Clause	Requirement + Test	Result - Remark	Verdict

Test item particulars .... :	
Possible test case verdicts:	
- test case does not apply to the test object ....:	N/A
- test object does meet the requirement ....:	P (Pass)
- test object does not meet the requirement ....:	F (Fail)
- test object was completed per the requirement...:	C(Complete)
- test object was completed with modification……:	M(Modification)
Testing ....:	
Date of receipt of test item ....:	
Date (s) of performance of tests ....:	
General remarks:	
"(See Enclosure #)" refers to additional information appended to the report. "(See appended table)" refers to a table appended to the report. **Throughout this report a point is used as the decimal separator.**	
Manufacturer's Declaration of samples submitted for test:	
The applicant for this report includes samples from more than one factory location and a declaration from the Manufacturer stating that the sample(s) submitted for evaluation is (are) representative of the products from each factory has been provided ....:	☐ **Yes** ☐ **Not applicable**
Name and address of factory (ies) ....:	Samsung SDI 163, Bangudae-ro Samnam-eup, Ulju-gun Ulsan, Republic of Korea
General product information and other remarks: The E5S (MS3204L101A) lithium ion module sis manufactured by Samsung SDI. The module is rated 110.4Vdc and 290Ah. The module contains sixty CP1495L101A Samsung SDI cells arranged in a 30S/2P configuration.	

5.0	CONSTRUCTION		Verdict
5.2	Module Construction		—
5.2.1, 5.2.3	Construction information	See Test Item Description at the beginning of this report	—
	General layout of module contents	See Attachment B	—
5.2.2	Module certified to UL 1973	**Yes (MH49407)**	C
	Organization that certified module:	**UL Solutions**	—
6.0	**PERFORMANCE**		**Verdict**
6.1	**General**		
8.1	**Samples**		
8.1.1	Samples conditioned through charge discharge cycling a minimum of 2 cycles.	See Attachment A for profiles See Table 1 for specifications See also Table 2	C
8.1.2	100% SOC and stabilize from 1h to 8 h before testing		
8.1.3	Electronic controls such as BMS not relied upon during testing.		C
8.2	**Test Method**		
8.2.1	Ambient indoor laboratory conditions: 25 ±5°C (77 ±9°F) ≤50 ±25% RH at the initiation of the test.	See Table 3 See Attachment F	C
8.2.2	Test conducted under a smoke collection hood appropriately sized for the module		C
8.2.3	The weight of the module was recorded before and after testing, (kg)	See Attachment F and Table 11	C
8,2,4	A sufficient number of cells were forced into thermal runaway to create a condition of cell to cell propagation within the module.	See Attachment C and F See Tables 4 and 5	C
	The location of the cell(s) forced into thermal runaway were selected to present the greatest thermal exposure to adjacent cells	See Attachment C for figures showing location within the module of the cell(s) forced into thermal runaway	C
8.2.5	The method used to initiating thermal runaway in the cell(s) were in accordance with 7.2	See Summary of Cell Testing at the beginning of this report.	C
8.2.6	The occurrence of thermal runaway was verified	See Test Results from Cell Level Test from the beginning of this report See Attachments D and F	C

UL 9540A, Edition 4,			
Clause	Requirement + Test	Result - Remark	Verdict
8.2.7	The module was placed on top of a non-combustible horizontal surface with the module orientation representative of its intended final installation.	See Attachment E	C
8.2.8	The chemical heat release rate of the module was measured with oxygen consumption calorimetry	See Table 10 See Attachment F and G	C
8.2.9	The chemical heat relate rate was measured for the duration of the test	See Attachment F and G	C
8.2.10	The chemical heat release rate was measured using the following equipment: ● Paramagnetic oxygen analyser ● Non-dispersive infrared carbon dioxide and carbon monoxide analyser ● Velocity probe ● Type K thermocouple	See Attachment G	C
	The instrumentation was located in the exhaust duct of the heat release rate calorimeter at a location that minimizes the influences of bends or exhaust devices.		C
8.2.11	The chemical heat release rate at each of the flows was calculated in accordance with 8.2.11.	See Attachment G	C
8.2.12	The hydrocarbon content of the vent gas was measured using flame ionization detection.	See Table 8 and 9	C
	Hydrogen gas shall be measured with a palladium-nickel thin-film solid state sensor.	See Table 9. The hydrogen measurement system malfunctioned during the test, however, the same module design was tested with different charging specifications and the hydrogen was below detectable limits.	C

UL 9540A, Edition 4,			
Clause	Requirement + Test	Result - Remark	Verdict
8.2.13	The hydrocarbon content of the vent gas may also be measured using a Fourier-Transform Infrared Spectrometer with a minimum resolution of 1 cm-1 and a path length of at least 2 m (6.6 ft), or equivalent gas analyzer.	See Attachment G FTIR analysis was not used in accordance with the Certification Requirement Decision: Corrections to gas measurement methods to make FTIR as an option for measuring hydrocarbon contents of gas emissions and to include Hydrogen measurements during the Unit Level Test. FTIR was considered redundant to the other gas measurement methods used	C
	Vent gas velocity and temperature measurements respectively were obtained in the exhaust duct of the heat release rate calorimeter using equipment specified in 8.2.10.		C
8.2.14	The light transmission in the exhaust duct of the heat release rate calorimeter was measured using a white light source and photo detector for the duration of the test.		C
8.2.15	Smoke release rate was calculated as outlined in 8.2.15	See Table 10 See Attachment G	C
8.3	**Module level test report**		
	a. Module manufacturer and model number; b. Number of cells in module; c. Module configuration;	See Test Item Description in beginning of this report.	C
	d. Module construction features;	See Attachment C See Critical Components Table ☐ See Also “Description of components employed within the module that impact propagation (fire protection features)” at the beginning of this report.	C
	e. Module voltage corresponding to the tested SOC;	See Table 3 See Attachment F	C
	f. Thermal runaway initiation method used;	See Attachment C and F	C
	g. Heat release rate versus time data;	See Table 10 See Attachment G	C
	h. Flammable gas generation and composition data;	See Attachment F and G See Tables 8 and 9	C

UL 9540A, Edition 4,			
Clause	Requirement + Test	Result - Remark	Verdict

	i. Peak smoke release rate and total smoke release data.	See Table 10 See Attachment F	C
	j. Observation(s) of flying debris or explosive discharge of gases;	See Attachment F and Table 12	C
	k. Observation(s) of sparks, electrical arcs, or other electrical events;	See Attachment F and Table 12	C
	l. Identification/location of cells(s) that exhibited thermal runaway within the module;	See Tables 4 and 5	C
	m. Locations and visual estimations of flame extension and duration from the module;	See Attachments E and F See Table 7	C
	n. Module weight loss;	See Table 11	C
	o. Video of the test.	Videos were recorded and stored in UL database at the request of Samsung SDI. However, the snapshots of the test are provided in the report. See Attachments E	C
8.4	**Performance – Module level**		
8.4.1	The following performance conditions are met during the module level test: a) Thermal runaway is contained by module design;	External flaming was observed.	F
	b) Cell vent gas is nonflammable as determined by the cell level test	The vent gas is flammable.	F

UL 9540A, Edition 4,			
Clause	Requirement + Test	Result - Remark	Verdict

Table 1 – Specified conditioning parameters			
Charging:		**Discharging:**	
Current (CC), A	58.0	Current (CC), A	58.0
Standard full Charge Voltage, Vdc	124.5	End of discharge voltage, Vdc	93.0
End of charge current, A	58.0	Discharging Test Ambient, °C	23 ± 5
Charging Test Ambient, °C	23 ± 5		
Refer to Attachment A for charge/discharge profiles for the module.			

Table 2 – Charge completion and module test initiation times	
Charge Completion Date and Time	**Module Test Date and Time**
2023/04/10 / 13:33:41	2023/04/12 / 15:20:17

Table 3 - Test Initiation Details	
	Module No.:
Test Date	2023/04/12
Test Start Time	15:20:17
Initial Lab Temperature	25.6 °C
Initial Relative Humidity	36.5%
Module OCV at Start of Test, Vdc	123.28

Table 4 – Approximate time of thermal runaway propagation through module		
Location	**Event**	**Time (HH:MM:SS)**
Initiating Cell	Thermal Runaway	0:46:14
Cell 35	First cell propagation	0:58:04
Cell 31	Second cell propagation	1:13:49
Propagation	Propagation of instrumented cells throughout the module	0:58:04 ~ 5:02:20

Table 5 – Test overview timeline		
Time (HH:MM:SS)	**Event**	**Description**
00:00:00	Test Start	Test started – The initiating cells temperature was increase at a rate of 5 °C/minute until thermal runaway occurred. The thermocouple on the side of the cell not covered by the heater was used to monitored to control the heating rate.
00:45:26	Vent	Gas vented from the module and the temperature of the initiating cell suddenly decreased.

00:46:14	Thermal Runaway	Gas vented from the top of the module above the initiating cell venting area in 48 seconds after the venting. The temperature of the cell increase in an uncontrollable manner at 00:46:14 into the test. At this time dark smoke and sparks exited the module above the initiating cell vent area.
00:46:15	Ignition	One second after thermal runaway the gas/smoke exiting the top of the module above the initiating cell vent area ignited.
0:58:04 ~ 05:25:28	Propagation	Cell to cell propagation occurred on instrumented cells.
02:39:45	Maximum Heat Release Rate	Maximum heat release rate was observed. 1,872 kW connective HRR and 3,935 kW chemical HRR.
05:25:28	Flaming End	No further flames were observed after 5:25:28.
05:29:15	Test Terminated	Video recording was stopped at 05:29:15 after test start. However, the sample remained in the testing room overnight and no further thermal runaway or re-ignition was observed.

UL 9540A, Edition 4,			
Clause	Requirement + Test	Result - Remark	Verdict

Table 6 – Gases measured and measurement methods used in unit level testing			
Measurement Method	**Gases Measured**	**Chemical Formula**	**Gas Type**
Flame Ionization Detection (FID)	Total Hydrocarbons	-	Hydrocarbons
Solid-state Hydrogen Sensor	Hydrogen	H_2	
Non-dispersive infrared spectroscopy (NDIR)	Carbon Dioxide	CO_2	Carbon Containing
	Carbon Monoxide	CO	Carbon Containing
[ ] Fourier-Transform Infrared Spectrometer (FTIR)	Acetylene	C_2H_2	Hydrocarbons
	Ethylene	C_2H_4	Hydrocarbons
	Methane	CH_4	Hydrocarbons
	Methanol	CH_3OH	Hydrocarbons
	Propane	C_3H_8	Hydrocarbons
	Formaldehyde	CH_2O	Hydrocarbons (Aldehydes)
	Hydrogen Bromide	HBr	Hydrogen Halides
	Hydrogen Chloride	HCl	Hydrogen Halides
	Hydrogen Fluoride	HF	Hydrogen Halides
	Ammonia	NH_3	Nitrogen Containing
	Hydrogen Cyanide	HCN	Nitrogen Containing
# - This table was modified to reflect the gases measured during testing.			

UL 9540A, Edition 4,			
Clause	Requirement + Test	Result - Remark	Verdict

Table 7 - Gas generation periods	
Time	**Condition**
0:45:26 – 0:46:15	Pre-Flaming
0:46:15 – 5:25:28	Flaming
External Flaming of Gas	
Condition	**Duration (hh:mm:ss)**
External Flaming of Vent Gases:	4:39:13

Table 8– Summary of battery gas volumes for deflagration hazard calculations				
Gas Component	Gas Type	During Pre-flaming (L)	During Flaming (L)	Minimum detectable flow rate(LPM)
Total Hydrocarbons (Propane Equivalent)	Hydrocarbons	6.61	677.14	0.04
Carbon Dioxide	Carbon Containing	Below detectable limit	39542.50	3.11
Carbon Monoxide	Carbon Containing	Below detectable limit	1421.12	0.44
Hydrogen	Hydrogen	*	*	*

*The hydrogen measurement system malfunctioned during the test, however, the same module design was tested with different charging specifications and the hydrogen quantity was below detectable limits Please refer to the report under UL project 4790648531.

Table 8A – Summary of battery gas volumes identified during thermal runaway in module test			
Gas Component	**Gas Type**	**During Pre-flaming (L)**	**During Flaming (L)**
Carbon Dioxide	Carbon Containing		
Carbon Monoxide	Carbon Containing		
Ethylene	Hydrocarbons		
Methane	Hydrocarbons		

Table 9 – Smoke and heat release rate			
Heat Release Rate (HRR)		**Smoke Release Rate (SRR)**	
Peak Chemical HRR (kW)	3935	Maximum SRR (m^2/s)	7.06
		Total Smoke Released (m^2)	2702

Table 10 – Module Weight During Test, kg	
Before Test:	171.5
After Test:	81.2
Weight Loss:	90.3

Table 11 – Other Observations during module test		
	Observed, Yes/No	Location
Flying debris	Yes	Out of top of module during thermal runaways
Explosive discharge of gas	Yes	Started with venting area of the initiating cells.
Sparks or electrical arcs	Yes	Sparks above each cell venting area

TABLE: Critical components information					
Object / Part No.	**Manufacturer/ trademark**	**Type / model**	**Technical data**	**Standard**	**Mark(s) of conformity**
Cells	SAMSUNG SDI	CP1495L101A	145 Ah, 3.68 V	UL1973	RU (MH49407)
Case	-	-	Material SGCD 1.0T SGCD1.2T SGCC 2.0T	-	-
Plastic cover	LOTTE CHEMICAL CORPORATION	UF-1002	PC, 5VA, 80℃, Min Thickness: 2.50 mm	UL 746 UL 94	RU (E115797)
Hybrid busbar (Resin)	LOTTE CHEMICAL CORPORATION	TH-1100	PC, V-0, RTI[Elec]		

~~List of test equipment used:~~

~~A completed list of used test equipment shall be provided in the Test Reports when a Customer's Testing Facility has been used.~~

~~Clause~~	~~Measurement / testing~~	~~Testing / measuring equipment / material used, (Equipment ID)~~	~~Range used~~	~~Last Calibration date~~	~~Calibration due date~~

Test equipment recorded in internal UL Solutions database.

Attachment A: Module Conditioning (Charge/discharge) Profiles - (*Pages **19** through **20***)

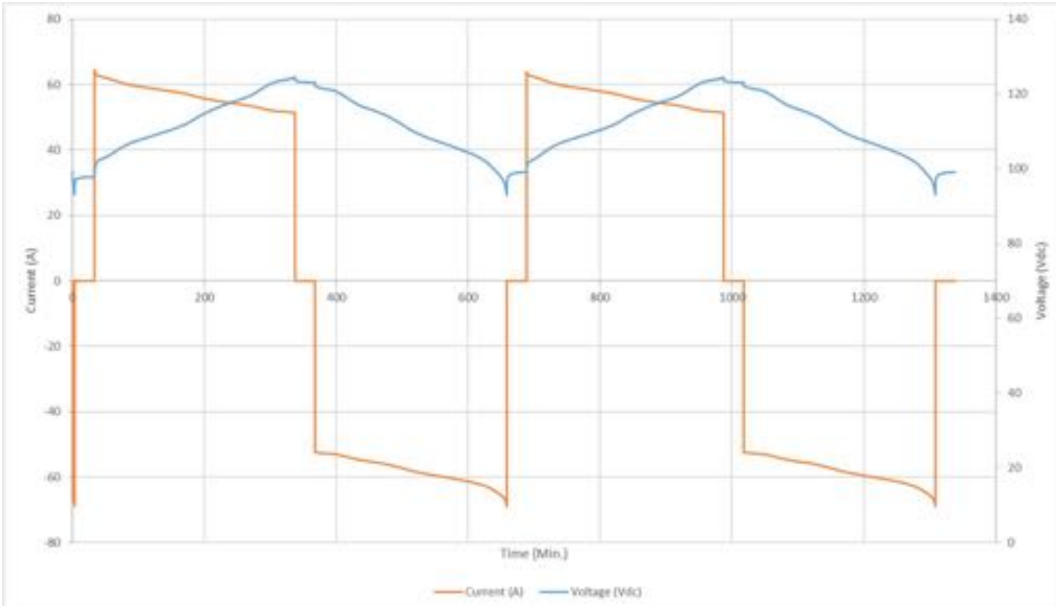


Figure A1 – Module Cycling

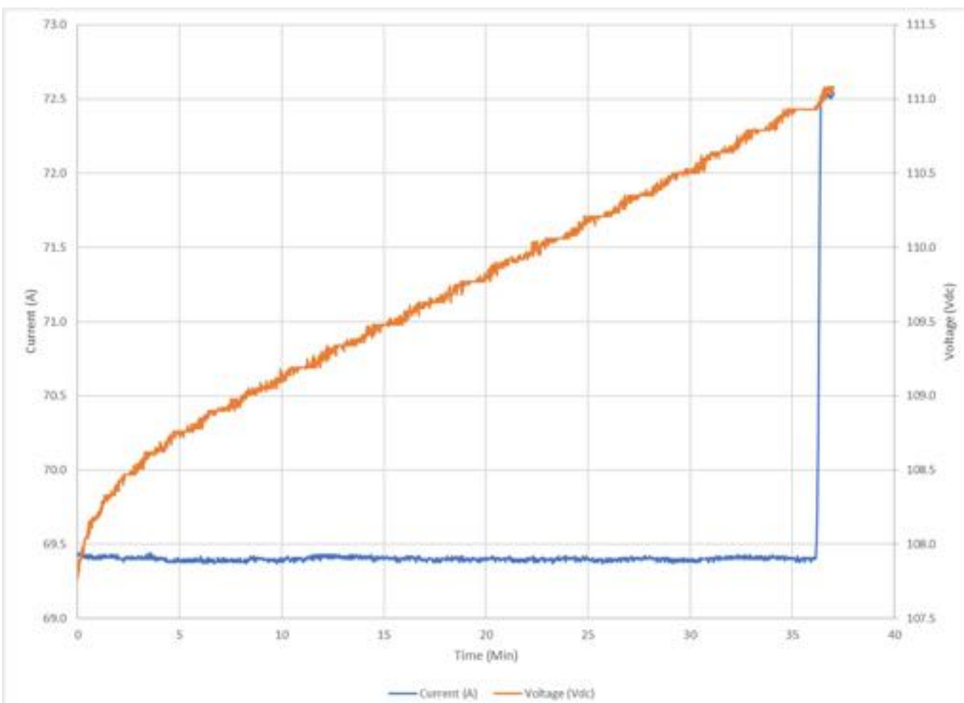


Figure A2: Module Charge Part 1

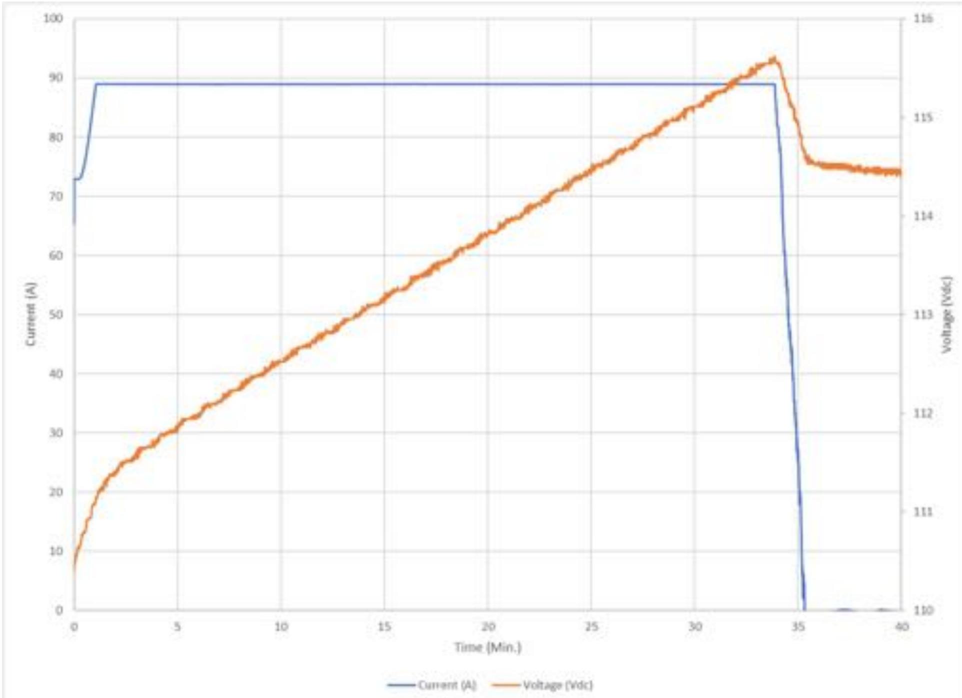


Figure A3: Module Charge Part 2 (At 34 minutes the charge ended and was restarted at a later time)

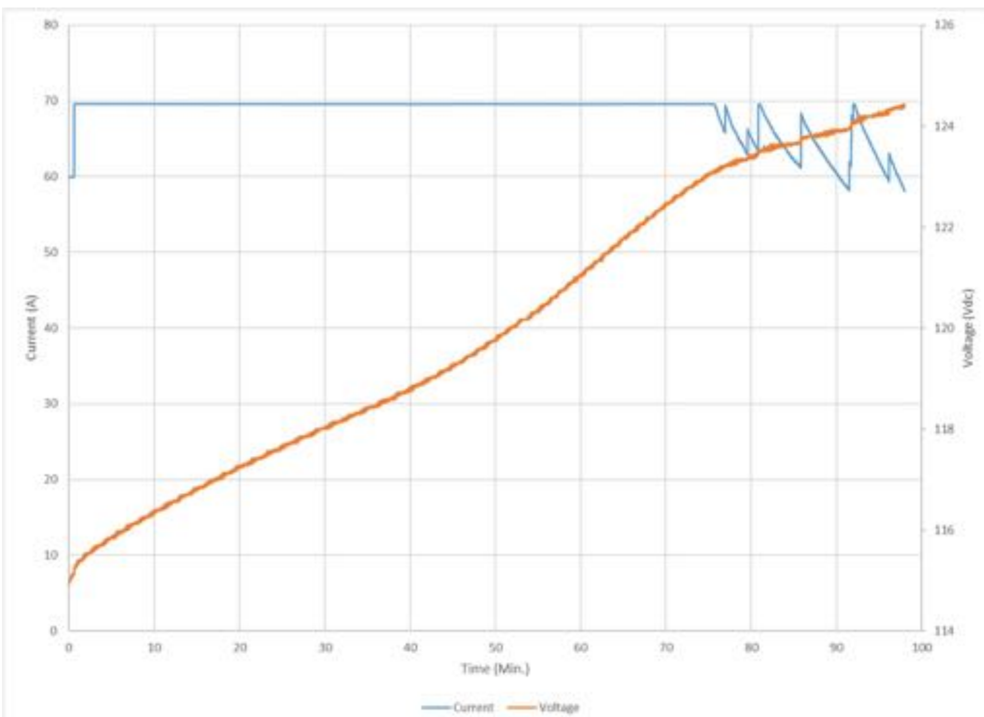


Figure A4: Module Charge Part 3

Attachment B: Module Construction Photos - (Pages ***21*** through ***22***)

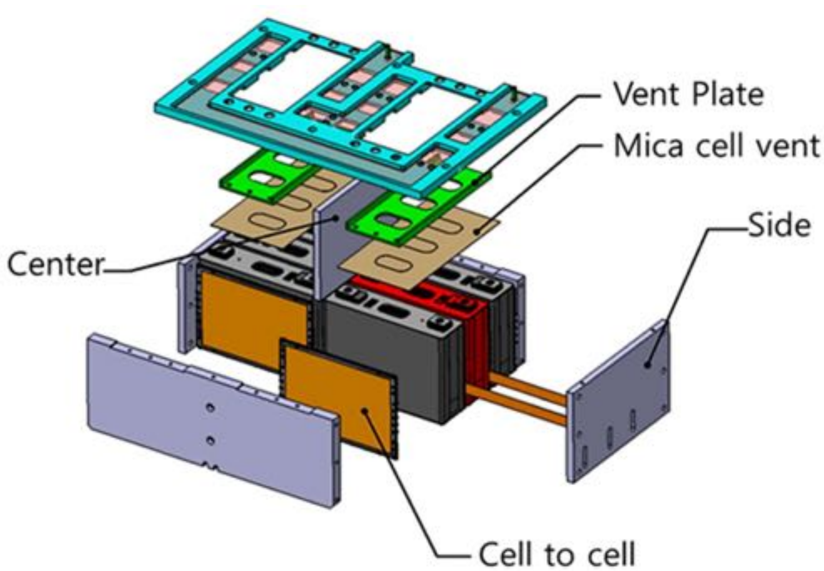


Figure B1: Component diagram

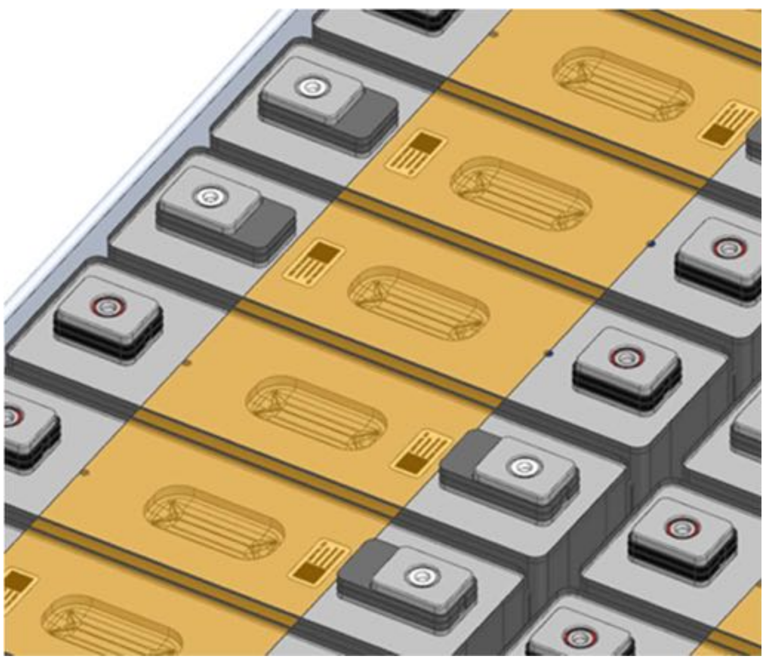


Figure B2: Cell layout

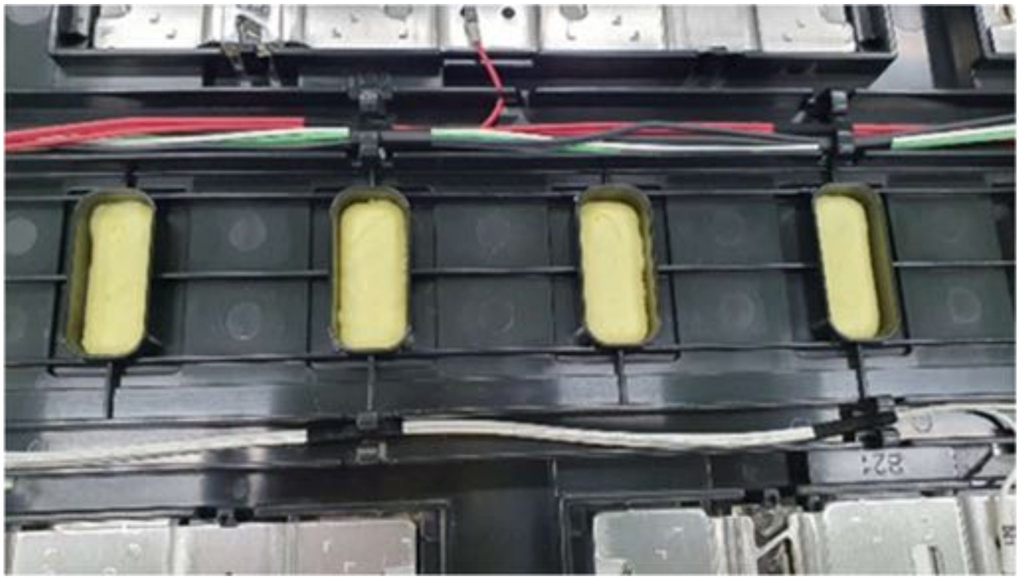


Figure B3: Cell vent

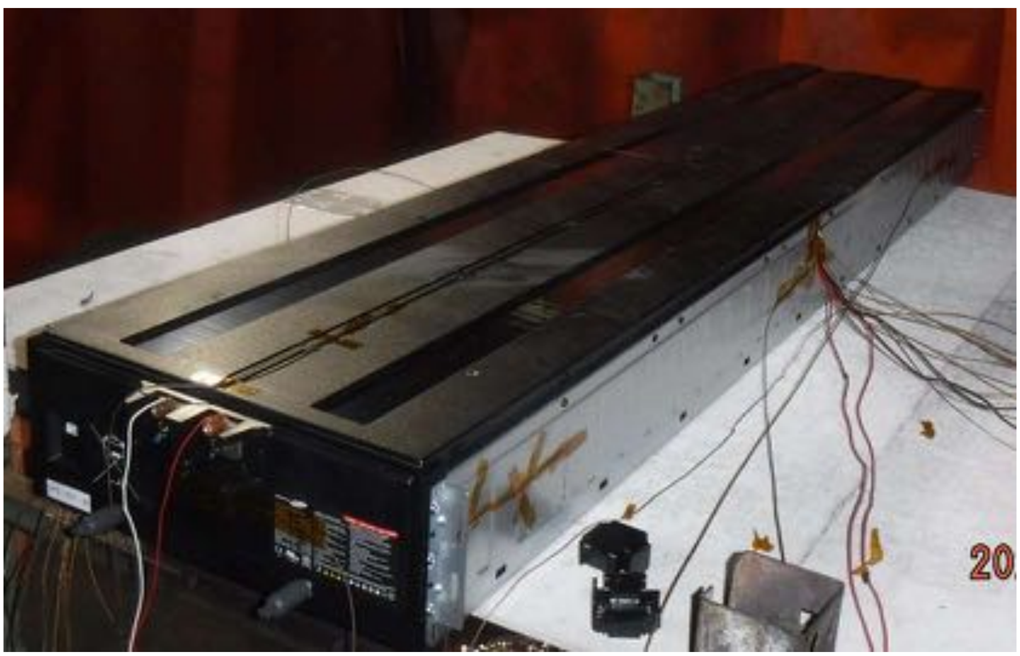


Figure B4: Overview of module

Attachment C: Module Instrumentation Photos - (*Pages **23** through **24***)

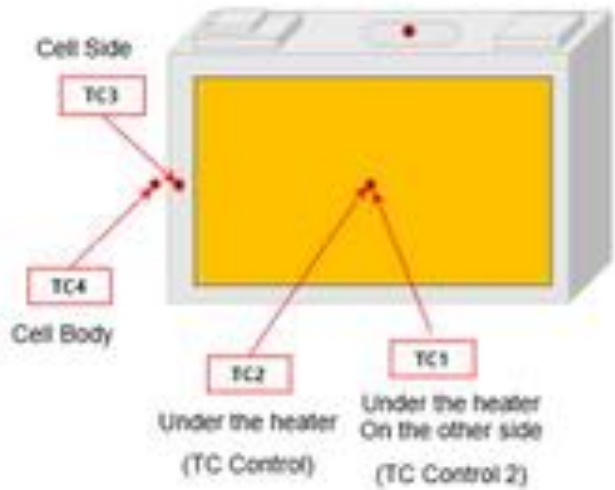


Figure C1: Cell Instrumentation

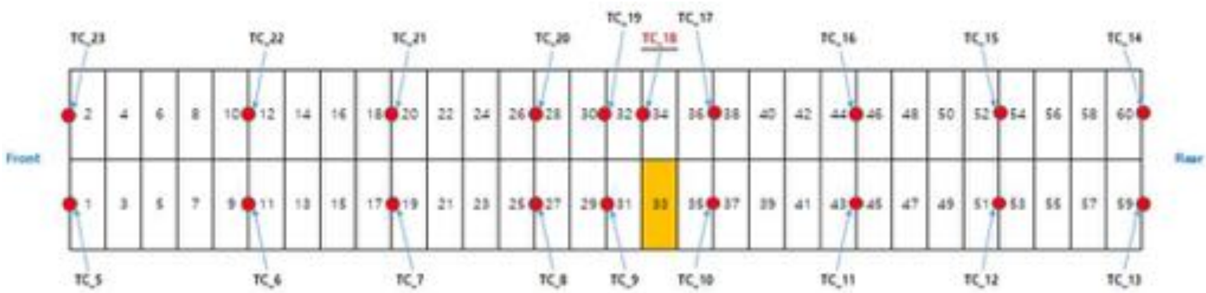


Figure C2: Module Cell Instrumentation

Figure C3: Left side module instrumentation

Figure C4: Right side module instrumentation

Figure C5: Rear module instrumentation

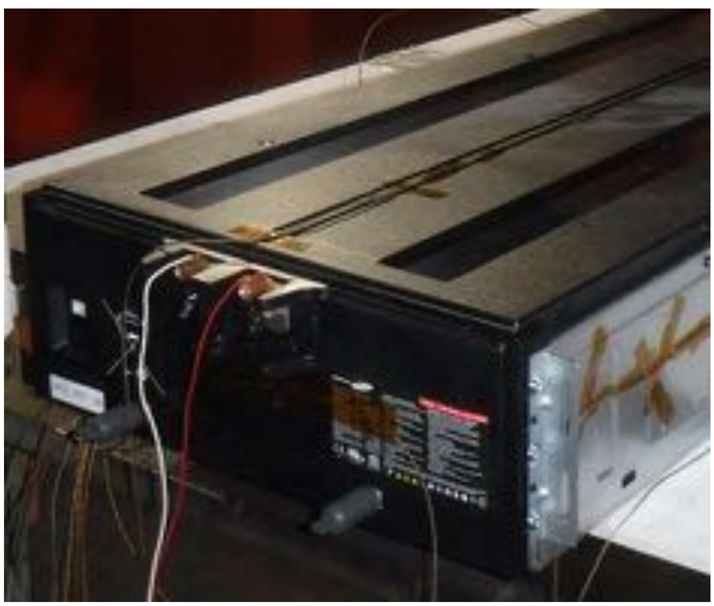


Figure C6: Front module instrumentation

Attachment D: Module and Initiating Cell(s) Temperature Profiles During Testing - (*Pages **25** through **26***)

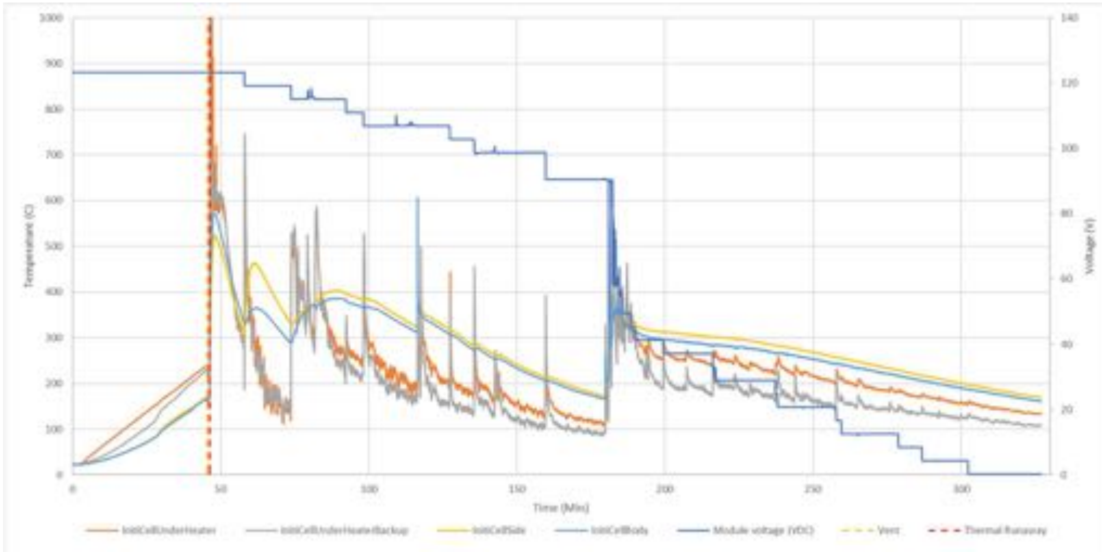


Figure D1: Initiating cell

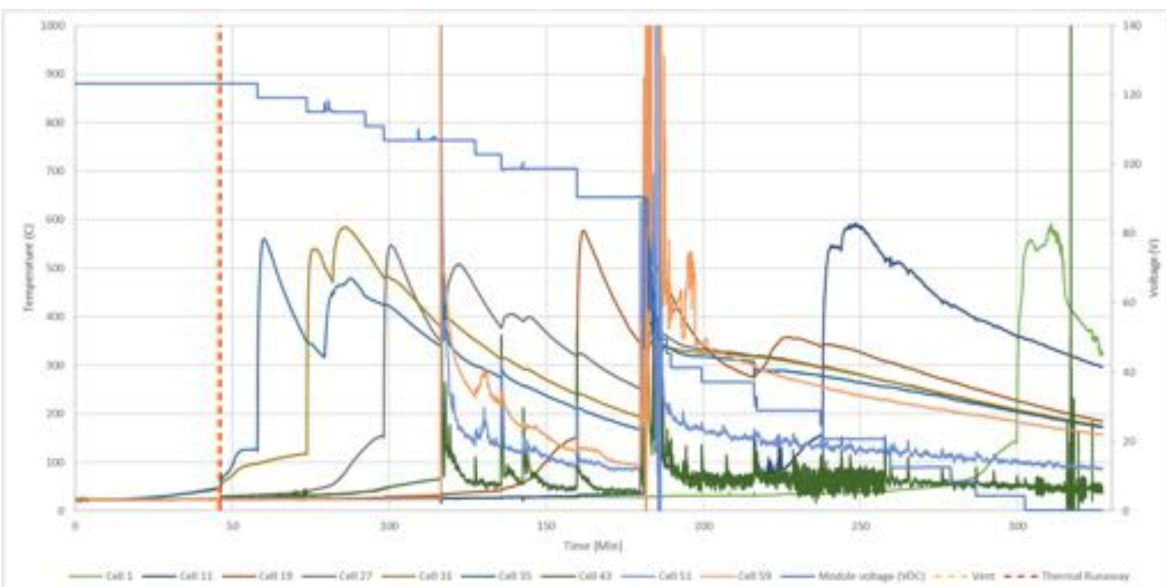


Figure D2: Cells in the initiating cell row

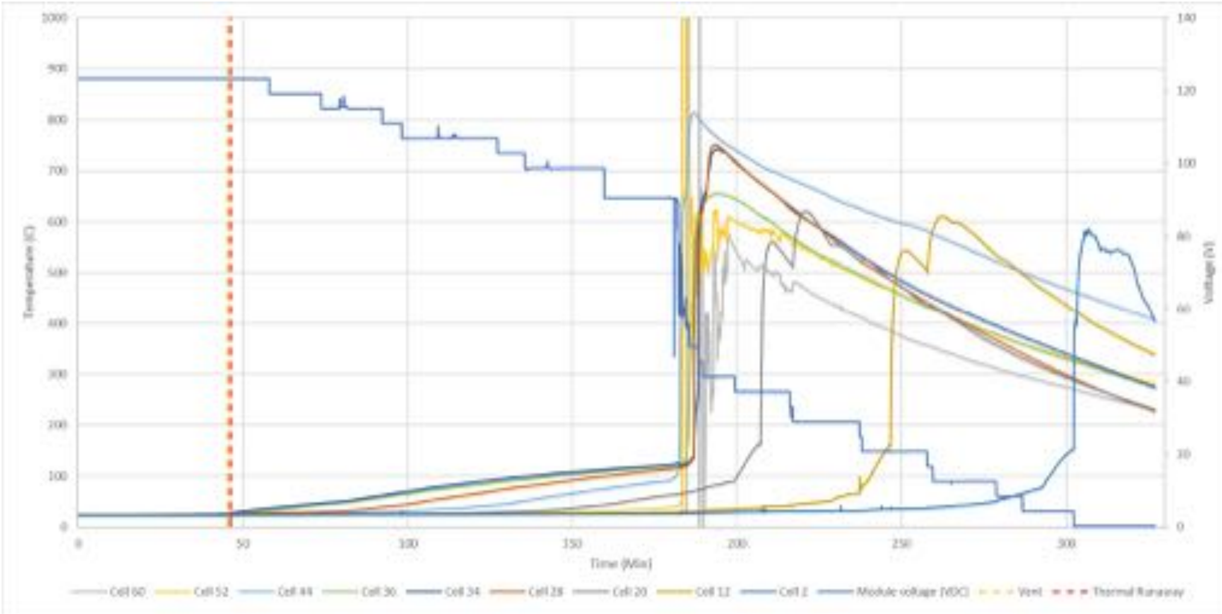


Figure D3: Cells in row without initiating cell

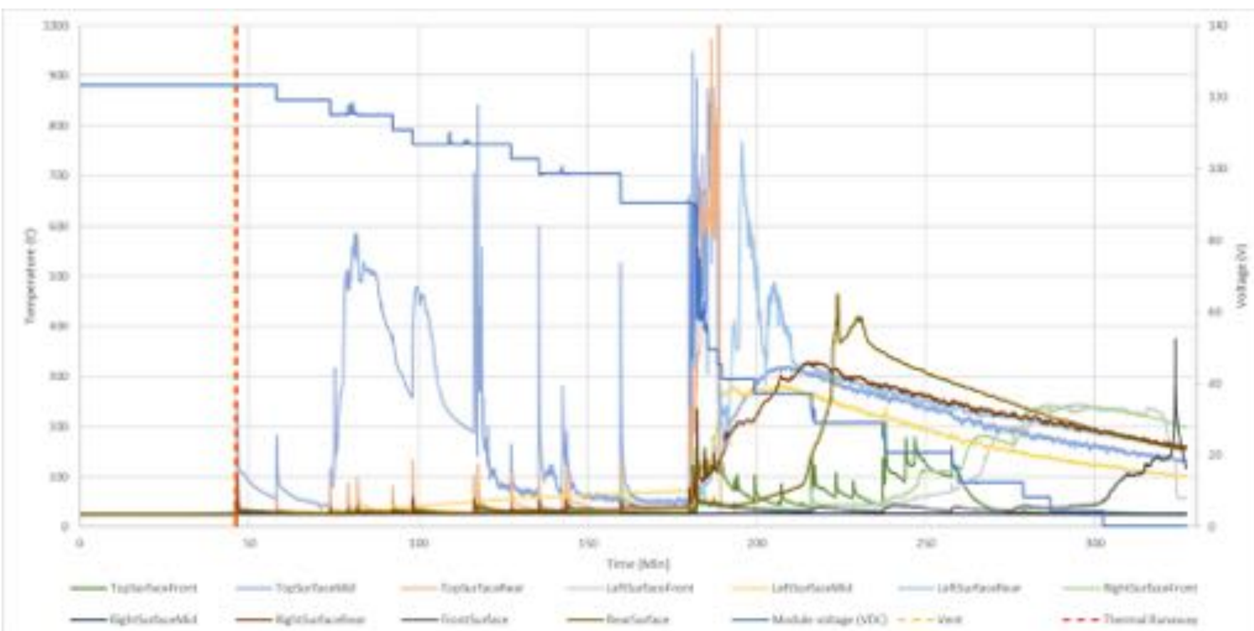


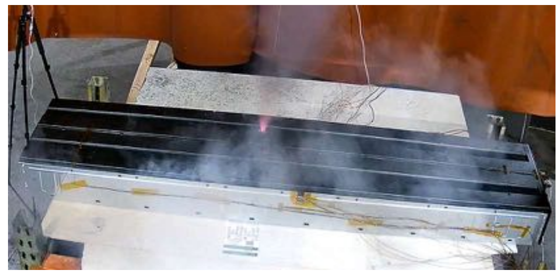
Figure D4: Exterior temperatures

Attachment E: Module Testing Photos - (*Pages **27** through **29***)


(a) Test Start
00:00:00


(b) Vent
00:45:26

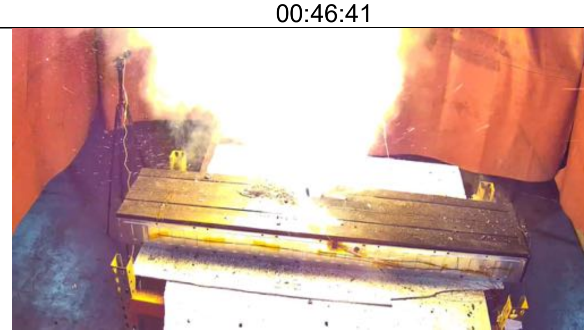

(c) Thermal Runaway (Initiating Cell)
00:46:14

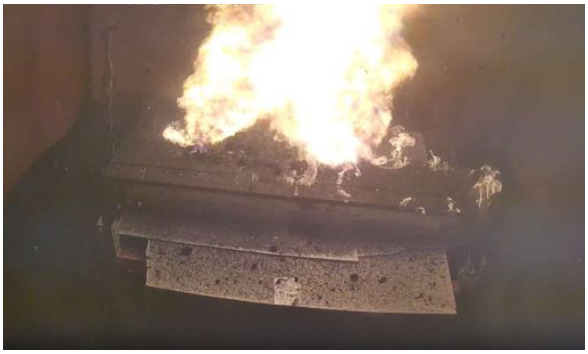
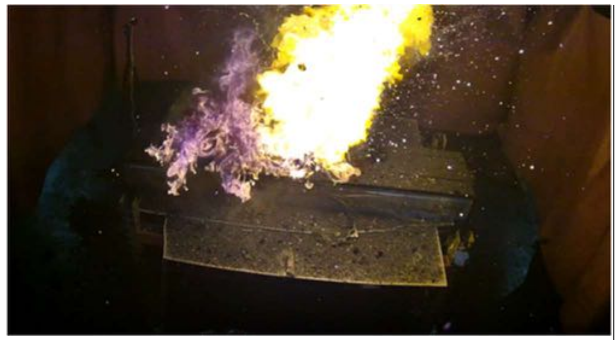

(d) First Flame
00:46:15


(e) Continuation of Initiating Cell Thermal Runaway
00:46:18


(f) Continued Flaming (post initiating cell thermal runaway)
00:46:41


(g) First propagation after Initiating Cell (Cell 35)
00:58:04


(h) Second propagation After Initiating Cell (Cell 31)
1:13:49

 (i) Maximum Chemical and Convective Heat Release Rate 02:39:45	 (j) Maximum Smoke Release Rate 03:07:07
 (k) Continued Thermal Runaway 04:35:51	 (l) Last Flame 05:25:28

Attachment F: Module Test Datasheets - (*Pages **30** through **30***)
Datasheet is stored internally in UL Solution's database.

Attachment G: Module Gas Flow Rate and Heat Release Profiles - (*Pages **31** through **32***)

*The hydrogen measurement system malfunctioned during the test, however, the same module design was tested with different charging specifications and the hydrogen quantity was below detectable limits – Please refer to the report under UL project 4790648531

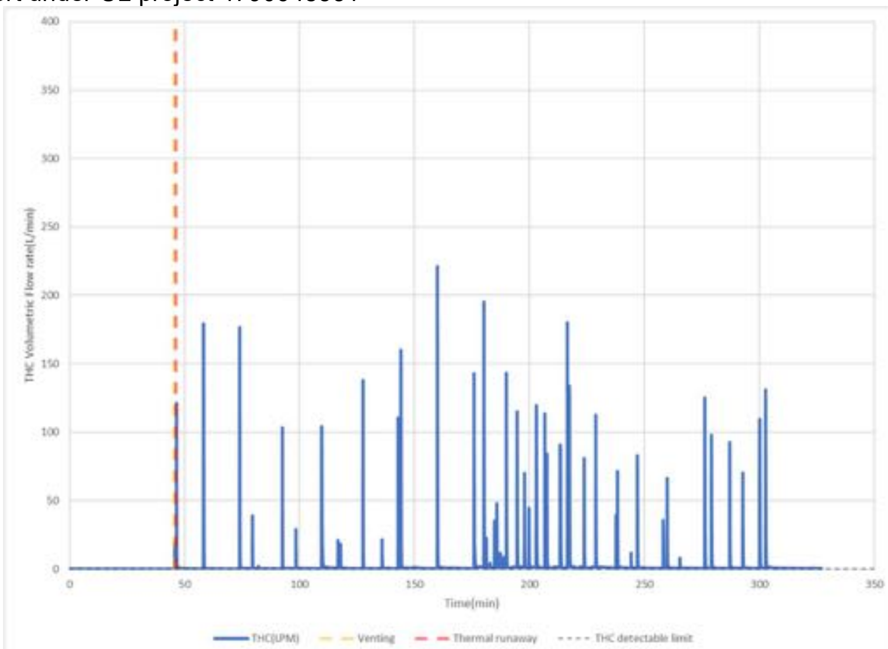


Figure G1 – Volumetric flow rates of gases (Total Hydrocarbon)

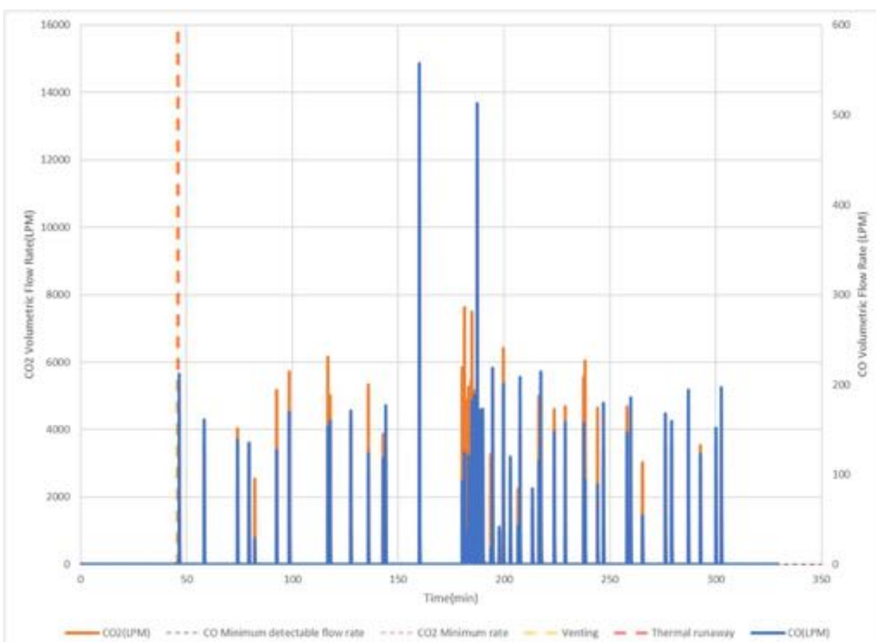


Figure G1 – Volumetric flow rates of gases (carbon monoxide and carbon dioxide)

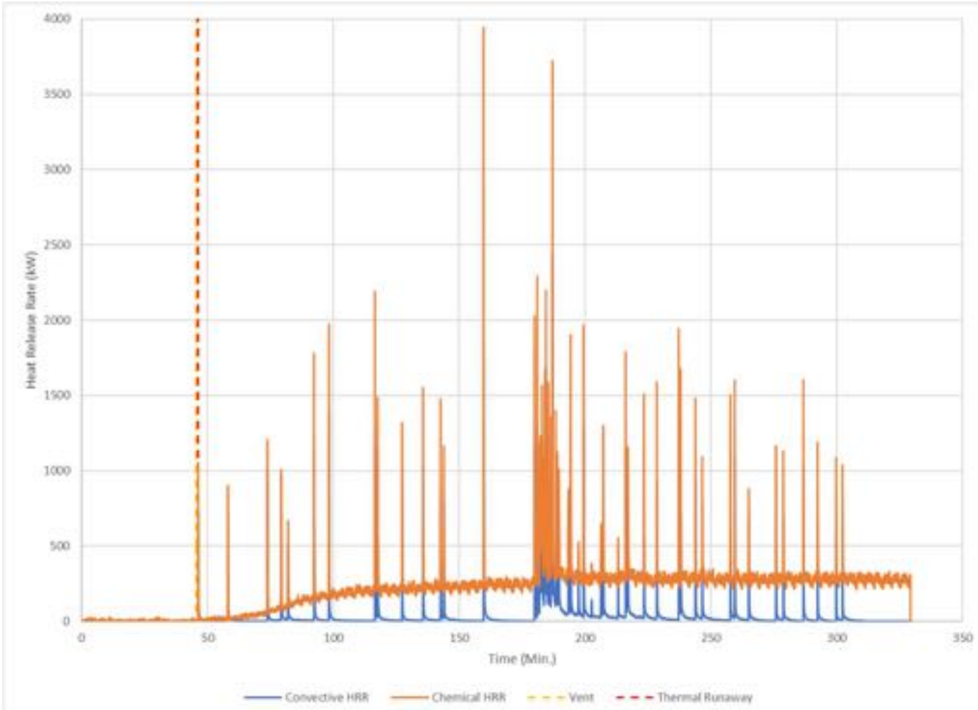


Figure G2 – Heat Release Rate

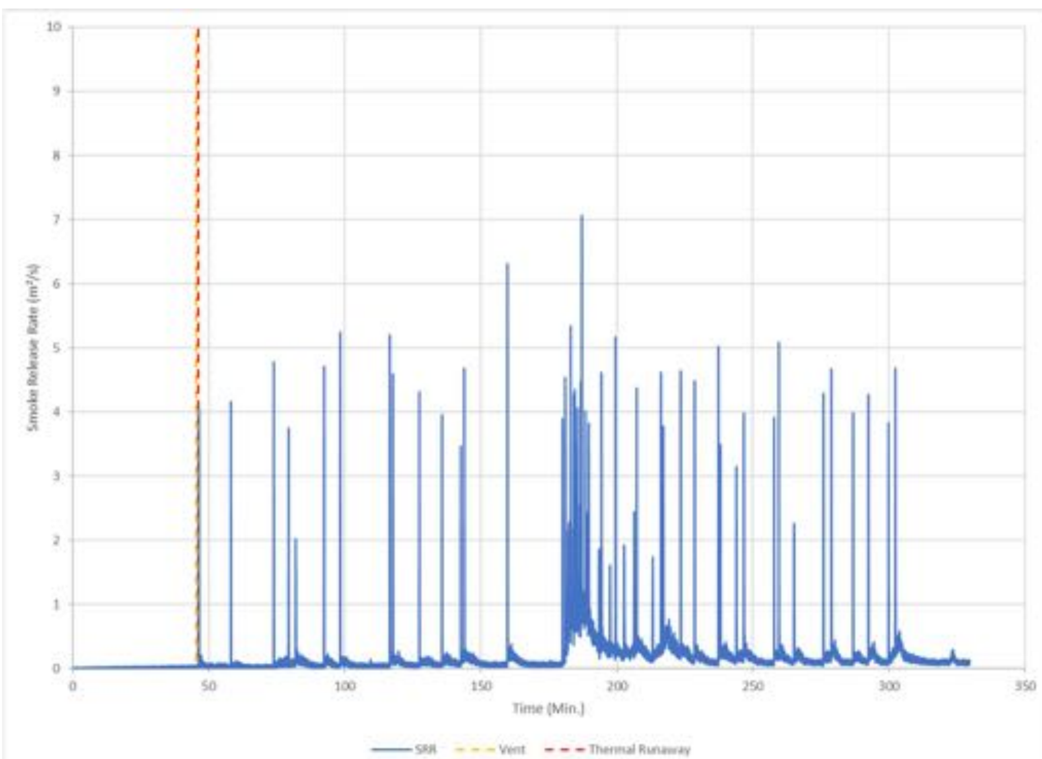


Figure G3 – Smoke Release Rate

Attachment H: Certification Requirement Decision - (*Pages **33** through **35***)

UNDERWRITERS LABORATORIES INC. CERTIFICATION REQUIREMENT DECISION

This Certification Requirement Decision is prepared by UL LLC. It is normative for the applicable UL Product Certification Program(s); however, it is currently not part of the UL Standard(s) referenced below.

Product Category (CCN): AACD
Standard Number: UL 9540A
Standard Title: Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems
Edition Date: November 12, 2019
Edition Number: 4
Section / Paragraph Reference: 7.3.1.5
Subject: Option to do a continuous thermal ramp until thermal runaway

DECISION:

7.3.1.5 Before beginning the test, a surface temperature shall be determined to approximate the temperature at which internal short circuiting within the cell will occur that could lead to a thermal runaway condition. For Li-ion cells, the surface temperature hold point shall be between 5°C (9°F) and 15°C (27°F) greater than the melting temperature of the cell separator material as determined from differential scanning calorimetry (DSC) data of the separator in accordance with UL 2591 (UL 746A). Thermal runaway may occur before this hold point temperature range is reached. However, if thermal runaway is not achieved at this hold point temperature after a period of 4 h, the cell heating rate according to 7.3.1.2 shall be reestablished until thermal runaway occurs or it is demonstrated that thermal runaway is not achievable by heating.

Exception: If the separator information is not available or at the manufacturer's discretion, the thermal ramp can be conducted continuously without a hold point until thermal runaway.

RATIONALE FOR DECISION:

The cell failure method had always been a thermal ramp until thermal runaway occurred. The hold temperature was established because of concern that if the thermal ramp continued at too high of a temperature, it may melt the cell casing. However, the separator information may not always be available and it may be just easier to conduct the test with a continuous thermal ramp if the client is in agreement. In either case, the goal is to establish a thermal runaway condition.

UNDERWRITERS LABORATORIES INC. CERTIFICATION REQUIREMENT DECISION

This Certification Requirement Decision is prepared by UL LLC. It is normative for the applicable UL Product Certification Program(s); however, it is currently not part of the UL Standard(s) referenced below.

Product Category (CCN): AACD
Standard Number: UL 9540A
Standard Title: Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems
Edition Date: November 12, 2019
Edition Number: 4
Section / Paragraph Reference: 8.12, 8.13, 9.24, 9.25, 10.3.13
Subject: Corrections to gas measurement methods to make FTIR as an option for measuring hydrocarbon contents of gas emissions and to include Hydrogen measurements during the Unit Level Test.

DECISION:

8.2.1~~1~~2 The hydrocarbon content of the vent gas shall be measured using flame ionization detection. Hydrogen gas shall be measured with a palladium-nickel thin-film solid state sensor.

8.2.1~~2~~3 The hydrocarbon components of the ~~V~~vent gas composition may additionally ~~shall~~ be measured using a Fourier-Transform Infrared Spectrometer with a minimum resolution of 1 cm-1 and a path length of at least 2 m (6.6 ft), or an equivalent gas analyzer~~,~~. ~~and v~~Velocity and temperature measurements respectively shall be obtained in the exhaust duct of the heat release rate calorimeter using equipment specified in 8.2.10.

9.2.24 The composition, velocity and temperature of the initiating BESS unit vent gases shall be measured within the calorimeter's exhaust duct as outlined in 8.2.10. The hydrocarbon content of the vent gas shall be measured using flame ionization detection. Hydrogen gas shall be measured with a palladium-nickel thin-film solid state sensor. ~~Gas composition shall be measured using a Fourier-Transform Infrared Spectrometer with a minimum resolution of 1 cm-1 and a path length of at least 2.0 m (6.6 ft), or equivalent gas analyzer.~~ Composition, velocity and temperature instrumentation shall be collocated with heat release rate calorimetry instrumentation.

9.2.25 The hydrocarbon content of the vent gas ~~shall~~ may additionally ~~also~~ be measured using ~~flame ionization detection.~~ a Fourier-Transform Infrared Spectrometer with a minimum resolution of 1 cm-1 and a path length of at least 2.0 m (6.6 ft), or equivalent gas analyzer.

10.3.13 The composition of BESS unit vent gases shall be measured as outlined in Section 9.2.24. The hydrocarbon content may additionally be measured as outlined in accordance with 9.2.25 ~~using a Fourier-Transform Infrared Spectrometer with a minimum resolution of 1 cm-1 and a path length of at least 2.0 m (6.6 ft), total hydrocarbon analyzer, and hydrogen analyzer.~~ The gas composition sampling port shall be located in the ceiling jet, 25-mm (1-in) below the ceiling.

RATIONALE FOR DECISION:

In the 4th edition of UL 9540A, there is redundancy in the two measurement methodologies used to characterize the volume of flammable gas released during module and unit level testing (Flame Ionization Detection (FID) and Fourier Transform Infrared Spectroscopy (FTIR)). Both FTIR and FID were developed as required measurements for module and unit level testing in the first three editions of UL 9540A before data existed that enabled an understanding of the typical compositions of battery gas. Both FID and FTIR were specified as requirements because it was not clear that FID alone would provide an adequate characterization of all flammable gases released by batteries in thermal runaway. Therefore, FTIR was first intended to provide a means to quantify non-hydrocarbon flammable gases as well as to serve as a backup for FID measurement. FTIR, to a lesser degree, was also identified as a potential backup or improvement for CO and CO_2. Experience has demonstrated that an improvement to CO and CO_2 measurement is not necessary and a backup to non-dispersive infrared spectroscopy (NDIR) measurement has not been needed. Therefore, the FTIR will remain in the standard but as an optional additional measurement method.

In addition, hydrogen is measured with a hydrogen specific sensor, because neither FID or FTIR are capable of measuring hydrogen.

The list of equipment in Table 1 demonstrates overlap in the methodologies used for gas measurement.

Table 1 – Gas measurement equipment for fire and explosion hazards

Gas Hazard	Measurement Equipment
Hydrocarbons	1. Total unburned hydrocarbons by flame ionization detector (FID) 2. Individual components by Fourier Transform infrared spectrometry (FTIR)
Carbon monoxide (CO), Carbon dioxide (CO_2)	1. Individual components by non-dispersive infrared spectrometry (NDIR) 2. Individual components by FTIR
Hydrogen	1. Hydrogen sensor

UNIT TEST REPORT
UL 9540A
Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems (AACD)

Project Number..............................:	**4790648531**
Date of issue ....:	**2023-06-28**
Total number of pages...................:	**56**
UL Report Office ....:	**UL Solutions** **333 Pfingsten Road** **Northbrook, IL 60062** **United States**
Applicant's name...........................:	**Samsung SDI Co Ltd**
Address ....:	**428-5 GONGSE-DONG GIHEUNG-GU** **YONGIN-SI, GYEONGGI-DO, 446-577** **KR**
Test specification:	4th Edition, Section 9, November 12, 2019
Standard...:	UL 9540A, Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems
Test procedure ....:	9.1 – 9.8
Non-standard test method ....:	

General disclaimer:

The test results presented in this report relate only to the sample tested in the test configuration noted on the list of the attachments.

UL LLC did not select the sample(s), determine whether the sample(s) was representative of production samples, witness the production of the test sample(s), nor were we provided with information relative to the formulation or identification of component materials used in the test sample(s).

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Cell level information	
Cells in Module:	
•Manufacturer Name	Samsung SDI
•Part Number	CP1495L101+
•Chemistry	Lithium-ion
•Format	Prismatic
Ratings (Vdc, Ah) :	3.68V, 145Ah
Cell certified? :	Yes
Standard the cell was certified to:	UL 1973
Organization that certified the cell:	UL Solutions (MH64496)
Average cell surface temperature at gas venting, °C:	166
Average cell surface temperature at thermal runaway, °C:	176
Gas Volume:	430.6
Lower flammability limit (LFL), % volume in air at the ambient temperature:	8.04
Lower flammability limits (LFL), % volume in air at the venting temperature:	6.74
Burning velocity (S_u) cm/s:	86.40
Maximum pressure (P_{max}) psig:	105.3

Cell level Gas Composition:

Gas	Measured %
Hydrogen	32.7
Carbon monoxide	40.9
Methane	15.43
Ethylene	0.56
Ethane	1.06
Carbon dioxide	9.2
Propene (Propylene)	0.04
Propane	0.03
C4 Total	0.05
C5 Total	0.01
Benzene	0.06
Total	**100**

Module level Information	
Model No... :	MS3204L101A
Ratings (Vdc, Ah)............................ :	110.4VDC, 290Ah
Module dimensions (X x **Y** x **Z** (mm))……………….:	388.2 x 1751.8 x 155.0 mm
Module cell configuration (xS/yP) ……:	30S/2P
Module weight (kgs)………………………. :	173
Module enclosure material……………….. :	Plastic Cover : PC(M3020PN), 2.5T Mica Sheet 0.3t(&Aerogel) Sheet
Was the module certified? …………………………..:	Yes
Standard the module was certified to …………..:	UL 1973
Organization that certified test item …….:	UL Solutions (MH64496)
Number of initiating cells failed to achieve propagation.	1
Thermal Runaway Propagation:	Yes
External Flaming:	Yes
Location(s) of Flame Venting:	Flaming out of the top of the module
Flying Debris:	Yes
Re-ignitions:	No reignitions
Test Maximum Smoke Release Rate (m^2/s)	7.06
Test Total Smoke Released: (m^2)	3516.04
Test Peak Chemical Heat Release Rate: (kW):	3935

Module level test Gas Composition & Volume for Each Compound (Pre-flaming and After flame) :

Gas Compound	Gas Type	Pre-Flaming (L)	Flaming (L)	Minimum detectable flow rate(LPM)
Total Hydrocarbons (Propane Equivalent)	Hydrocarbons	6.61	677.14	0.04
Carbon Monoxide	Carbon Containing	Below detectable limit	39542.50	3.11
Carbon Dioxide	Carbon Containing	Below detectable limit	1421.12	0.44
Hydrogen[1]	Hydrogen	Below detectable limit	Below detectable limit	0.00

[1] *The hydrogen measurement system malfunctioned during the test; however, the same module design was tested with different charging specifications and the hydrogen quantity was below detectable limits – Please refer to the report under UL project 4790648531

Unit level Information	
Model No. :	PHR3843-001A
Ratings (Vdc, Ah)............................ :	1324.8V, 290 Ah
BESS dimensions (W x **D** x **H** (mm)**)……………….:**	960.5 * 1752 * 2352 mm
BESS module configuration	12S/1P
Number of modules in BESS	24
Module cell configuration (xS/**y**P**) …...:**	30S/2P
Number of cells in module.:	60
BESS weight (kgs)………………………. :	2524 kg
BESS enclosure material……………….. :	Metal case, Plastic Cover, Mica(&Aerogel) sheet
BESS Intended Installation: **Non Residential:** outdoor ground mounted, indoor floor mounted, outdoor wall mounted, indoor wall mounted, roof top, open garage **Residential:** Outdoor ground mounted, indoor floor mounted, outdoor wall mounted, indoor wall mounted	Non-Residential indoor floor mounted.
Residential Indoor Use: Smallest volume room installations specified.	N/A
Original Equipment Manufacturer (OEM):	Samsung SDI Co LTD
Branding Manufacturer (if not OEM):	N/A
Was the unit certified? …………………………:	Yes
Standard the unit was certified to …………..:	UL 1973
Organization that certified the unit …….:	UL Solutions (MH49407)
Cell failure test method performed (summary of method and test clause): ☒ External heating using thin film with 4°C to 7°C thermal ramp. ☐ Nail Penetration ☐ Overcharge ☐ External short circuit (***X*** Ω *external resistance*) ☐ Others	
Description of method used to fail cells if other than external thin film heater with thermal ramp, : N/A	
Description of components employed within the BESS unit that serve to suppress propagation (fire protection features) The BESS Unit includes a smoke detection and NOVEC system as a fire suppression system. Once smoke is detected, a signal (signals from two smoke detectors) is sent to the fire control panel , which will open the solenoid valve on the NOVEC cylinder for NOVEC to be released into the integral suppression system pipes.	
Deviation from the module level test N/A	
Number of initiating cell(s)	1
Thermal Runaway Propagation:	No

External Flaming from BESS:	Yes
Location(s) of Flame Venting:	Front and Rear Top Surface
Maximum Target BESS Temperature, °C	20
Maximum Wall Surface Temperature[2], °C	172
Peak Chemical Heat Release Rate, kW	426
Peak Convective Heat Release Rate, kW	191
Maximum Smoke Heat Release Rate, m^2/s	1.1
Maximum Heat Flux on Target Modules, kW/m^2	0.70
Maximum Heat Flux of Egress Path, kW/m^2	6.74
Flying Debris:	No flying debris
Re-ignitions:	No reignitions

Gas Analysis:

☒ Flame ionization detection (FID)

☒ Non-Dispersive Infrared Spectrometer (NDIR)

☐ Fourier-Transform infrared Spectrometer

☒ Hydrogen Sensor (palladium-nickel, thin-film solid state sensor)

☒ White light source with photo detector (smoke release rate)

Summary of Unit level test Gas Analysis Data:

Unit level Gas Composition & Volume for Each Compound (Pre-flaming and After flame):

Gas Compound	Gas Type	Pre-Flaming (L)	Flaming (L)	Minimum detectable flow rate(LPM)
Total Hydrocarbons (Propane Equivalent)	Hydrocarbons[3]	Inconclusive	Inconclusive	2.21
Carbon Dioxide	Carbon Containing	Below detectable limit	343.97	11.24
Carbon Monoxide	Carbon Containing	Below detectable limit	789	8.91
Hydrogen	Hydrogen	Below detectable limit	Below detectable limit	20.67

[2] Maximum wall surface temperature averaged on 60 seconds.
[3] The increase of THC is due to NOVEC released from the system as the THC was analysed with FID.

Summary of BESS Unit Test Results
Performance Criteria in accordance with Table 9.1 for Indoor Floor Mounted non-residential unit
[ ] Flaming outside the initiating BESS unit was not observed; **[X]** Surface temperatures of modules within the target BESS units adjacent to the initiating BESS unit did not exceed the temperature at which thermally initiated cell venting occurs, as determined in 7.3.1.8; **[ ]** For BESS units intended for installation in locations with combustible constructions, surface temperature measurements on wall surfaces did not exceed 97°C (175°F) of temperature rise above ambient per 9.2.15; **[X]** Explosion hazards were not observed, including deflagration, detonation or accumulation (to within the flammability limits in an amount that can cause a deflagration) of battery vent gases; and **[ ]** Heat flux in the center of the accessible means of egress did not exceed 1.3 kW/m^2.

Necessity for an Installation level test
[X] The performance criteria of the unit level test as indicated in Table 9.1 of UL 9540A 4th edition has not been met, therefore an installation level testing in accordance with UL 9540A will need to be conducted on the representative the installation with this unit installed. **[ ]** The performance criteria of the unit level tests as indicated in Table 9.1 of UL 9540A 4th edition has been met, therefore an installation level testing in accordance with UL 9540A need not be conducted.

Testing Laboratory Information		
Testing Laboratory and testing location(s):		
Testing Laboratory:	UL Solutions	
Testing location/ address............................:	333 Pfingsten Road Northbrook, IL 60062 United States	
Tested by (name, signature) ....:	Jonathon Depasque	
Project Handler (name, signature)..............:	Bryan Chang	[signature]
Reviewer (name, signature) …………….:	Sean Yang	[signature]

List of Attachments (including a total number of pages in each attachment):
Attachment A: Sample Charging, OCV and SOC Measurement Profiles - (*Pages **25** through **28***)
Attachment B: BESS (including module and any integral fire detection and suppression systems) Construction Photos/Diagrams - (*Pages **29** through **32***)
Attachment C: BESS and Equipment Instrumentation and Test Installation Layout Photos/Diagrams - (*Pages **33** through **41***)
Attachment D: Temperature Profiles and Heat Flux Measurements During Testing (Initiating Cell and Module, Target Modules, Wall Surfaces, etc. - (*Pages **42** through **46***)
Attachment E: BESS Unit Testing and Post Testing Photos - (*Pages **47** through **50***)
Attachment F: BESS Unit Gas Flow Rate and Heat Release and Smoke Release Profiles - (*Pages **51** through **54***)
Attachment G: Certification Requirement Decision - (*Pages **55** through **56***)

Photo(s) of BESS unit:

Test Item Charge/Discharge Specifications:	
• Charge current, A:	90.0
• Standard Full charge voltage, Vdc:	124.5
• Charge temperature range, °C:	23 ± 5°C
• End of charge current, A:	58.0
• Discharge current, A:	58.0
• End of discharge voltage, Vdc:	93.0
• Discharge temperature range, °C:	23 ± 5°C

Test item particulars ....:	
Possible test case verdicts:	
- test case does not apply to the test object...........:	N/A
- test object does meet the requirement ....:	P (Pass)
- test object does not meet the requirement...........:	F (Fail)
- test object was completed per the requirement...:	C(Complete)
- test object was completed with modification……:	M(Modification)
Testing..:	
Date of receipt of test item ....:	2023-03-27
Date (s) of performance of tests ....:	2023-04-06

General remarks:

"(See Enclosure #)" refers to additional information appended to the report.
"(See appended table)" refers to a table appended to the report.

Throughout this report a point is used as the decimal separator.

Manufacturer's Declaration of samples submitted for test:

The applicant for this report includes samples from more than one factory location and a declaration from the Manufacturer stating that the sample(s) submitted for evaluation is (are) representative of the products from each factory has been provided ....:	☐ **Yes** ☒ **Not applicable**
Name and address of factory (ies) ....:	163, Bangudae-ro, Samnam-myeon, Ulju-gun, Ulsan, 689-710, Republic of Korea

General product information and other remarks:

The BESS Unit, Model PHR3843-001A, is composed of 12 MS3204L101A modules, rated 110.4V, 290Ah, in series Each module is composed of 60 cells in a 2P/30S configuration. Each cell, Model CP1495L101A, is rated 3.68V, 145Ah. The BESS Unit also includes a smoke detection and NOVEC system as a fire suppression system. Once smoke is detected, a signal is sent to the NOVEC system for NOVEC to be released into the BESS unit. The released NOVEC is intended to prevent thermal runaway propagation.

5.0	CONSTRUCTION		Verdict
5.3	**Battery energy storage system unit Construction**		—
5.3.1, 5.3.2	Construction information	See Test Item Description at the beginning of this report	—
5.3.2	General layout of BESS unit contents	See Attachment B	—
5.3.3	Details of integral fire suppression system	BESS Unit is installed with smoke detectors and a NOVEC System. Once smoke is detected, NOVEC is released to the system to cool down the modules.	
5.3.1	BESS certified to UL 9540	No	
	Organization that certified BESS:	N/A	—
6.0	**PERFORMANCE**		**Verdict**
6.1	**General**		
9.1	**Sample and test configuration**		
9.1.1	The unit level test conducted with BESS units installed as described in the manufacturer's instructions.	See Attachment C for test installations Installation type: Non-residential, indoor floor mounted.	C
9.1.2	The unit level test required one initiating BESS unit in which an internal fire condition in accordance with the module level test is initiated and target adjacent BESS units representative of an installation.	See Attachment C for test installations	C
	Tests conducted for indoor floor mounted installations are representative of both indoor floor mounted and outdoor ground mounted installations.	BESS Units are not intended for outdoor use.	N/A
	Tests conducted indoors with fire propagation hazards and separation distances between initiating and target units representative of the installation.	The distance between the initiating and target units is 0[mm].	C

UL 9540A, Edition 4,			
Clause	Requirement + Test	Result - Remark	Verdict
	Testing conducted outdoors for outdoor only installations with following in place: a) Wind screens with wind speed of ≤ 12 mph; b) Temperature range is 10°C to 40°C (50°F to 104°F); c) Humidity is < 90% RH; d) Sufficient light to observe the testing; e) There is no precipitation; f) There is control of vegetation and combustibles in the test area; and g) There are protection mechanisms in place to prevent inadvertent access by unauthorized persons in the test area.		C
9.1.3	Testing to determine fire characterization was done at the battery system level rather than a complete BESS		C
9.1.4	The initiating BESS contained components representative of a BESS unit in a complete installation.		C
	Combustible components that interconnect the initiating and target BESS units was included.		C
9.1.5	Target BESS units include the outer cabinet (if part of the design), racking, module enclosures, and components that retain cells components.		C
9.1.6	The initiating BESS was at the maximum operating state of charge (MOSOC),	See Table 2 and Attachment A	C
	After charging and prior to testing, the initiating BESS was at rest for a maximum period of 8 hours at room ambient.	See Table 2. The voltage of the initiating module was checked within 8 hours after charging and right before the test and no voltage drop was found. Based on this fact and at the request of Samsung, re-charging was not performed	M
9.1.7	The BESS unit included an integral fire suppression system.	The BESS units are installed with smoke detectors and a NOVEC System.	C
9.1.8	Electronics and software controls such as the battery management system (BMS) are not relied upon for this testing.		C
	Included a fire suppression control in accordance with UL 864 that is external to the BESS.	Fire suppression system is designed with the BESS.	N/A
9.2	**Test method – Indoor floor mounted BESS units**		

UL 9540A, Edition 4,			
Clause	Requirement + Test	Result - Remark	Verdict
9.2.1	Test room ambient temperature within 10°C (50°F) to 32°C (90°F).	See Table 2.	C
9.2.2	Access door(s) or panels on the initiating BESS unit and adjacent target BESS units were closed, latched and locked duration of the test.	The BESS units do not utilize doors or latches.	N/A
9.2.3	The initiating BESS unit was positioned adjacent to two instrumented wall sections.	See Attachment C.	C
9.2.4	Instrumented wall sections extend not less than 0.49 m (1.6 ft) horizontally beyond the exterior of target BESS units.		C
9.2.5	Instrumented wall sections were at least 0.61-m (2-ft) taller than the BESS unit height, but not less than 3.66 m (12 ft) in height above the bottom surface of the unit.		C
9.2.6	The surface of the instrumented wall sections was covered with 16-mm (5/8-in) gypsum wall board and painted flat black.	See Attachment C.	C
9.2.7	The initiating BESS unit was centred underneath an appropriately sized smoke collection hood of an oxygen consumption calorimeter.		C
9.2.8	The light transmission in the calorimeter's exhaust duct was measured using a white light source and photo detector. The smoke release rate was calculated.	See Table 12. See Attachment F.	C
9.2.9	The chemical and convective heat release rates were measured for the duration of the test.	See Table 12. See Attachment F.	C
9.2.10	The heat release rate measurement system was calibrated using an atomized heptane diffusion burner. The calibration was performed using flows of 3.8, 7.6, 11.4 and 15.2 L/min (1, 2, 3 and 4 gpm) of heptane.		C
9.2.11	The chemical heat release rate was measured using the following equipment: ● Paramagnetic oxygen analyser ● Non-dispersive infrared carbon dioxide and carbon monoxide analyser ● Velocity probe ● Type K thermocouple		C
9.2.12	The chemical heat release rate at each of the flows was calculated.		C
9.2.13	The physical spacing between BESS units (both initiating and target) and adjacent walls was representative of the intended installation.	See Attachment C.	C

UL 9540A, Edition 4,			
Clause	Requirement + Test	Result - Remark	Verdict
9.2.14	Separation distances were specified by the manufacturer for distance between: a) The BESS units and the instrumented wall sections; and b) Adjacent BESS units.	See Attachment C.	C
9.2.15	Wall surface temperature measurements were collected	See Table 6. See Attachment D.	C
	The intended installation is composed completely of non-combustible construction		C
9.2.16	Wall surface temperatures were measured in vertical array(s) at 152-mm (6-in) intervals for the full height of the instrumented wall sections using No. 24-gauge or smaller, Type-K exposed junction thermocouples.		C
	The thermocouples for measuring the temperature on wall surfaces were horizontally positioned in the wall locations to receive greatest thermal exposure from the initiating BESS unit.		C
9.2.17	Thermocouples were secured to gypsum surfaces and the thermocouple tip was depressed into the gypsum so as to be flush with the gypsum surface at the point of measurement .		C
9.2.18	Heat flux was measured with at least two water-cooled Schmidt-Boelter gauges at the surface of each instrumented wall: a) Both are collinear with the vertical thermocouple array; b) One is positioned to receive the greatest heat from the initiating module; and c) One is positioned to receive the greatest heat flux during potential propagation within the initiating BESS unit.		C
9.2.19	Heat flux was measured with 2 water-cooled Schmidt-Boelter gauges at the surface of each adjacent target BESS units facing initiating BESS unit: a) One is positioned at the elevation estimated to receive the greatest heat flux from the initiating module; and b) One is positioned at the elevation estimated to receive the greatest surface heat flux due to initiating BESS.		C

UL 9540A, Edition 4,			
Clause	Requirement + Test	Result - Remark	Verdict
9.2.20	Heat flux was measured with the sensing element of at least one water-cooled Schmidt-Boelter gauge positioned in the center of the accessible means of egress.		C
9.2.21	No. 24-gauge or smaller, Type-K exposed junction thermocouples were installed to measure the temperature of the surface proximate to the cells and between the cells and exposed face of the initiating module.	See Attachment C	C
	Each non-initiating module enclosure within the initiating BESS unit was instrumented with at least one No. 24-gauge or smaller Type-K thermocouple(s) within non-initiating modules.	See Attachment C	C
	Additional thermocouples were placed to account for convoluted geometries.		C
9.2.22	For residential use, the DUT was covered with a single layer of cheese cloth ignition indicator. The cheesecloth was untreated cotton cloth running 26 – 28 m2/kg with a count of 28 – 32 threads in either direction within a 6.45 cm^2 (1 in^2) area.		N/A
9.2.23	An internal fire condition in accordance with the module level test was created within a single module in the initiating BESS unit: a) The position selected to present the greatest thermal exposure to adjacent modules; and b) The setup was the same as that used to initiate and propagate thermal runaway within the module level test.	See Attachment C	C
9.2.24	The composition, velocity and temperature of the initiating BESS unit vent gases was measured within the calorimeter's exhaust duct. Composition, velocity and temperature instrumentation shall be collocated with heat release rate calorimetry instrumentation.		C
	Hydrogen gas shall be measured with a palladium-nickel thin-film solid state sensor.		C
	The hydrocarbon content of the vent gas may also be measured using a Fourier-Transform Infrared Spectrometer with a minimum resolution of 1 cm-1 and a path length of at least 2 m (6.6 ft), or equivalent gas analyzer.	See Attachment F.	N/A
9.2.25	The hydrocarbon content of the vent gas was measured using flame ionization detection.	See Tables 8, 9, 10 and 11.	C

UL 9540A, Edition 4,			
Clause	Requirement + Test	Result - Remark	Verdict

9.7	**Unit level test report**		
9.7.1	Installation type tested:		C
9.7.2	Testing is intended to represent more than one installation type.	See Test Item Description in beginning of this report.	C
9.7.3	a. Unit manufacturer name and model number (and whether UL 9540 compliant);		C
	b. Number of modules in the initiating BESS unit		C
	c. BESS construction features;	See Attachment C. See Critical Components Table. ð See Also “Description of components employed within the module that impact propagation (fire protection features)” at the beginning of this report.	C
	d. Fire protection features/ detection/ suppression systems within unit		C
	e. Module voltages corresponding to the tested SOC;	See Table 13. See Attachment A.	C
	f. Thermal runaway initiation method used;	See Attachment C.	C
	g. Location of the initiating module within the BESS unit;	See Attachment C.	C
	h. Diagram and dimensions of the test setup including mounting location of the initiating and target BESS units, and the locations of walls, ceilings, and soffits;	See Attachment C.	C
	i. Observation of any flaming outside the initiating BESS enclosure and the maximum flame extension;	See Table 14.	C
	j. Chemical and convective heat release rate versus time data;	See Table 11. See Attachment F.	C
	k. Separation distances from the initiating BESS unit to target walls	See Attachment C	C
	l. Separation distances from the initiating BESS unit to target BESS units	See Attachment C	C
	m. The maximum wall surface and target BESS temperatures achieved during the test and the location of the measuring thermocouple;	Tables 5 and 6.	C
	n. The maximum ceiling or soffit surface temperatures achieved during the indoor or outdoor wall mounted test and the location of the measuring thermocouple;	Table 6.	C
	o) The maximum incident heat flux on target wall surfaces and target BESS units;	Table 7.	C

UL 9540A, Edition 4,			
Clause	Requirement + Test	Result - Remark	Verdict
	p) The maximum incident heat flux on target ceiling or soffit surfaces achieved during the indoor or outdoor wall mounted test;	Table 7.	C
	q. Flammable gas generation and composition data;	See Attachment F. See Tables 7, 8, 9, and 10.	C
	r. Peak smoke release rate and total smoke release data.	See Table 12. See Attachments F.	C
	s. Indication of the activation of integral fire protection systems and if activated the time into the test at which activation occurred;	Table 13 See Attachment D.	C
	t. Observation(s) of flying debris or explosive discharge of gases;	See Attachment E and Table 15 .	C
	u. Observation of re-ignition(s) from thermal runaway events	See Attachment E and Table 16.	C
	v. Observation(s) of sparks, electrical arcs, or other electrical events;	See Attachment E and Table 15.	C
	w. Observations of the damage to: 1) The initiating BESS unit; 2) Target BESS units; 3) Adjacent walls, ceilings, or soffits;	See Attachment E and Table 16.	C
	x. Video of the test.	The videos were provided to Samsung on the testing date.	C
9.8	**Performance at Unit level testing**		
9.8.1	Installation level testing in Section 10 was not required if the following performance conditions outlined in Table 9.1 are met during the unit level test.		F

UL 9540A, Edition 4,			
Clause	Requirement + Test	Result - Remark	Verdict

Non-Residential Installations – Indoor floor mounted:			
	a) Flaming outside the initiating BESS unit is not observed;	Flaming was observed outside the initiating unit.	F
	b) Surface temperatures of modules within target BESS units do not exceed the cell venting temperature;	The maximum surface temperature of the modules in the Target Units was 31°C.	P
	c) For BESS units intended for installation in locations with combustible constructions, surface temperature measurements on wall surfaces do not exceed 97°C (175°F) rise above ambient;	The maximum surface temperature on the walls was 169°C.	F
	d) Explosion hazards are not observed, including deflagration, detonation or accumulation (to within the flammability limits in an amount that can cause a deflagration) of battery vent gases;	An explosion was observed during the test.	P
	e) Heat flux in the center of the accessible means of egress did not exceed 1.3 kW/m^2.	The heat flux gauge in line with the initiating module in the front wall measured 6.74kW/m^2.	F

Table 1 – Specified Unit charging and discharging parameters			
Charging:		**Discharging:**	
Current (CC), A	90.0	Current (CC), A	58.0
Standard Full Charge Voltage, Vdc	124.5	End of discharge voltage, Vdc	93.0
End of charge current, A	58.0	Discharging Test Ambient, °C	23 ± 5
Refer to Attachment A for charge/discharge profiles.			

Table 2 - Test Initiation Details	
Test Date	2023-04-06
Test Start Time (HH:MM:SS)	13:26:04
Initial Lab Temperature, °C	30
Initial Relative Humidity % RH	19
Module OCV at Start of Test, Vdc	124

Table 3 – Approximate time of thermal runaway propagation through module			
Locations (Cell #)	**Event**	**Time**	**Temperature of the cell**
Cell 33	Vent	00:42:17	164
Cell 33	Thermal Runaway	00:42:25	179

Table 4 – Test overview timeline		
Time (HH:MM:SS)	**Event**	**Description**
00:00:00	Test Start	Start of the Test, the thermocouple located on the side of the cell was used to monitor the temperature ramp to be within 4 to 7 °C/minute.
00:42:17	Initiating Cell Vent	Venting of Initiating Cell; Based on the temperature data, a sudden temperature dip was observed which was the indication of venting from the cell level test. Venting gas begins to release from the battery.
00:42:25	Initiating Cell Thermal Runaway	The initiating cell goes into thermal runaway; this was determined by the temperature rise in an uncontrollable manner indicating self-heating along with the gas released from the initiating module. . At this event, the power supply to the heaters was disconnected.
00:42:30	Ignition	External flaming was observed following thermal runaway of the initiating cell.
00:42:32	Two Seconds after Ignition	Following ignition, flaming was only observed above the initiating module.
00:42:30 – 00:47:39	External Flaming on the Camera	External flaming was observed following thermal runaway of the initiating cell on the camera installed in the rear wall. The external flaming on the camera lasts approximately for five minutes.

UL 9540A, Edition 4,			
Clause	Requirement + Test	Result - Remark	Verdict

00:42:29	Smoke Detection – Alarm LED Turns On	Following the release of venting gas, the smoke detectors located at the top of the BESS unit activate and sends a sign to the NOVEC System. The system would release NOVEC based on signals from two different smoke detectors, however, based on the video analysis, which was the only analysis available to identify the time of smoke detection, it was not inconclusive to pinpoint the second smoke detector sending the signal.
00:42:30	NOVEC Release	Once the system detects smoke, a signal is sent to the NOVEC system to release the NOVEC to the battery modules.
00:54:42 – 01:08:23	NOVEC Flowing Over	NOVEC was observed overflowing and evaporating from the initiating module.
03:00:51	Test End	The data recording was stopped; however, the units remained in the testing room overnight until all the temperatures went down to the ambient temperature before the disposal.

Table 5 - Maximum Temperatures in Target Units			
Cell vent temperature from cell test data, °C			166
Target Unit 1		**Target Unit 2**	
Module Location No.	Temperature (°C)	Module Location No.	Temperature (°C)
Module 1	19	Module 1	15
Module 2	17	Module 2	15
Module 3	18	Module 3	15
Module 4	17	Module 4	15
Module 5	17	Module 5	15
Module 6	16	Module 6	15
Module 7	16	Module 7	15
Module 8	18	Module 8	15
Module 9	19	Module 9	15
Module 10	17	Module 10	15
Module 11	17	Module 11	15
Module 12	20	Module 12	16

UL 9540A, Edition 4,			
Clause	Requirement + Test	Result - Remark	Verdict

Table 6 - Maximum Temperatures on Instrumented Wall					
Side Wall Temperatures					
Ambient Temperature: 39°C					
UL 9540A performance criteria, Ambient + 97°C: 127°C					
Height, mm (in)	Maximum Temperature (°C)	Height, mm (in)	Maximum Temperature (°C)	Height, mm (in)	Maximum Temperature (°C)
152.4 (6)	13	1371.6 (54)	13	2590.8 (102)	21
304.8 (12)	13	1524 (60)	13	2743.2 (108)	21
457.2 (18)	13	1676.4 (66)	13	2985.6 (114)	21
609.6 (24)	13	1828.8 (72)	13	3048 (120)	22
762 (30)	13	1981.2 (78)	13	3200.4 (126)	21
914.4 (36)	13	2133.6 (84)	14	3352.8 (132)	20
1066.8 (42)	13	2286 (90)	16	3505.2 (138)	21
1219.2 (48)	13	2438.4 (96)	21		
Front Wall Temperatures					
Height, mm (in)	Maximum Temperature (°C)	Height, mm (in)	Maximum Temperature (°C)	Height, mm (in)	Maximum Temperature (°C)
152.4 (6)	35	1371.6 (54)	101	2590.8 (102)	37
304.8 (12)	56	1524 (60)	78	2743.2 (108)	35
457.2 (18)	74	1676.4 (66)	71	2985.6 (114)	30
609.6 (24)	172	1828.8 (72)	63	3048 (120)	23
762 (30)	165	1981.2 (78)	61	3200.4 (126)	20
914.4 (36)	155	2133.6 (84)	53	3352.8 (132)	22
1066.8 (42)	119	2286 (90)	47	3505.2 (138)	19
1219.2 (48)	89	2438.4 (96)	44		
Note: Temperatures are measured constantly and then averaged every 60-seconds					

Table 7 – Heat Flux Measurements			
Summary of maximum heat flux in target units		Summary of maximum heat flux measured on instrumented walls	
Maximum Heat Flux, kW/m^2			
Target Module No. 1:	0.01	Heat Flux Gauge No.	kW/m^2
Target Module No. 2:	0.70	Side Wall (Mid-Height)	0.01
		Side Wall (Initiating Module)	0.04
		Front Wall (Mid-Height)	6.74
		Front Wall (Initiating Module)	4.20

Table 8 – Gases measured and measurement methods used in unit level testing			
Measurement Method	**Gases Measured**	**Chemical Formula**	**Gas Type**
Flame Ionization Detection (FID)	Total Hydrocarbons	-	Hydrocarbons
Solid-state Hydrogen Sensor	Hydrogen	H_2	
Non-dispersive infrared spectroscopy (NDIR)	Carbon Dioxide	CO_2	Carbon Containing
	Carbon Monoxide	CO	Carbon Containing
~~[ ] Fourier-Transform Infrared Spectrometer (FTIR)~~	~~Acetylene~~	~~C_2H_2~~	~~Hydrocarbons~~
	~~Ethylene~~	~~C_2H_4~~	~~Hydrocarbons~~
	~~Methane~~	~~CH_4~~	~~Hydrocarbons~~
	~~Methanol~~	~~CH_3OH~~	~~Hydrocarbons~~
	~~Propane~~	~~C_3H_8~~	~~Hydrocarbons~~
	~~Formaldehyde~~	~~CH_2O~~	~~Hydrocarbons (Aldehydes)~~
	~~Hydrogen Bromide~~	~~HBr~~	~~Hydrogen Halides~~
	~~Hydrogen Chloride~~	~~HCl~~	~~Hydrogen Halides~~
	~~Hydrogen Fluoride~~	~~HF~~	~~Hydrogen Halides~~
	~~Ammonia~~	~~NH_3~~	~~Nitrogen Containing~~
	~~Hydrogen Cyanide~~	~~HCN~~	~~Nitrogen Containing~~
# - This table was modified to reflect the gases measured during testing.			

Table 9 - Gas generation periods	
Time	**Condition**
00:42:17 – 00:42:25	Pre-Flaming
00:42:25 – 03:00:51	Flaming
External Flaming of Gas	
Condition	**Duration (hh:mm:ss)**
External Flaming of Vent Gases:	00:05:09

Table 10 – Summary of battery gas volumes for deflagration hazard calculations				
Gas Component	Gas Type	During Pre-flaming (L)	During Flaming (L)	Minimum detectable flow rate(LPM)
Total Hydrocarbons (Propane Equivalent)	Hydrocarbons[4]	Inconclusive	Inconclusive	2.21
Carbon Dioxide	Carbon Containing	Below detectable limit	343.97	11.24
Carbon Monoxide	Carbon Containing	Below detectable limit	789	8.91
Hydrogen	Hydrogen	Below detectable limit	Below detectable limit	20.67

Table 11 – Smoke and heat release rate			
Heat Release Rate (HRR)		**Smoke Release Rate (SRR)**	
Peak Chemical HRR (kW)	426	Maximum SRR (m^2/s)	1.1
Peak Convective HRR, (kW)	191	Total Smoke Released (m^2)	269.37

Table 12 – Integral Fire suppression system Details of Operation		
Time of operation of Sprinklers/Suppression System:	Time of Operation Start (HH:MM:SS)	Length of Operation (HH:MM:SS)
Smoke Detection[5]	00:42:29	00:00:01
NOVEC Release	00:42:30	00:12:53

[4] The increase of THC is due to NOVEC released from the system as the THC was analysed with FID.
5 The system would release NOVEC based on signals from two different smoke detectors, however, based on the video analysis, which was the only analysis available to identify the time of smoke detection, it was not inconclusive to pinpoint the second smoke detector sending the signal.

UL 9540A, Edition 4,			
Clause	Requirement + Test	Result - Remark	Verdict

Table 13 - Module OCV voltage measurement comparison before and after testing			
Module Location In Rack	OCV Prior to Test (V)	OCV Post Test (V)	Difference (V)
1	122.50	122.49	0.01
2	122.40	122.40	0.00
3	122.40	122.40	0.00
4	122.70	122.67	0.03
5	122.70	122.67	0.03
6	122.60	122.56	0.04
7	122.48	122.48	0.00
8	122.31	122.30	0.01
9	122.60	122.30	0.30
10 (Initiating)	123.10	122.78	0.32
11	122.55	122.55	0.00
12	122.40	122.40	0.00

Table 14 – Other Observations during Unit test		
	Observed, Yes/No	Comments/Location
Flaming outside of Unit	Yes	Flaming was observed at the front and rear of the initiating module.
Flying debris	No	
Explosive discharge of gas	Yes	
Sparks or electrical arcs	No	

Table 15 - Post Test Observations	
Thermal runaway behaviour	Yes
Re-ignitions	No reignitions
Explosions	No explosions
Other Observations	Batteries exhibited thermal runaway behaviour during disposal

UL 9540A, Edition 4,			
Clause	Requirement + Test	Result - Remark	Verdict

TABLE: Critical components information					
Object / Part No.	**Manufacturer/ trademark**	**Type / model**	**Technical data**	**Standard**	**Mark(s) of conformity**
Cell	SAMSUNG SDI	CP1495L101A	145 Ah, 3.68 V	UL1973	UL Approved (MH64496)
Module	SAMSUNG SDI	MS3204L101A	2P30S, 32.016kWh	UL 1973	RU (MH49407)
Unit Enclosure	SAMSUNG SDI	PHR3843-001A	2P360S 384.192kWh	UL 1973	RU (MH49407)
Rack Assembly (for module, BCU both)	TEXON CO., LTD	SGHC / SGCC	t3.2, W960.5, L1752.0, H2352.0	-	-
Internal Wiring	JHOSIN HONGLIN TECHTRON	Type3817	AWG1, 125℃	UL 758	UL Approved (E115797)
Thermal Insulating Materials	Hanjung NCS	Mica, Aerogel	-	-	-
Smoke Detectors	POTTER	PAD300-PD	Addressable Smoke Detector	UL 268	Listed (S24776)
Fire Control Panel	POTTER	IPA-100	Addressable FACP	UL 864	Listed (S735)
Suppressant	3M	FK-5-1-12, 3MTMNovecTM1230 Fire Protection Fluid	>50kg of Novec Fluid, 360psi with nitrogen	-	-
NOVEC cylinder	GFI	F1230-CYL-58	-	-	-
Swaged Nipple Assy	GFI	SQF2S-1-7/ 8-12UN-OF1.5-SDI-S6	Orifice 1.50	-	-
Solenoid Valve	Fiwarec	F1120045	- 20 to 50 ℃	UL 864	UL Approved (S35768)
Plastic plug	LOTTE Chem	PP J-320	-	-	-
Pipes	Hanjung NCS	Brass	3/8”	-	-

Attachment A: Sample Charging, OCV and SOC Measurement Profiles - (*Pages **25** through **28***)

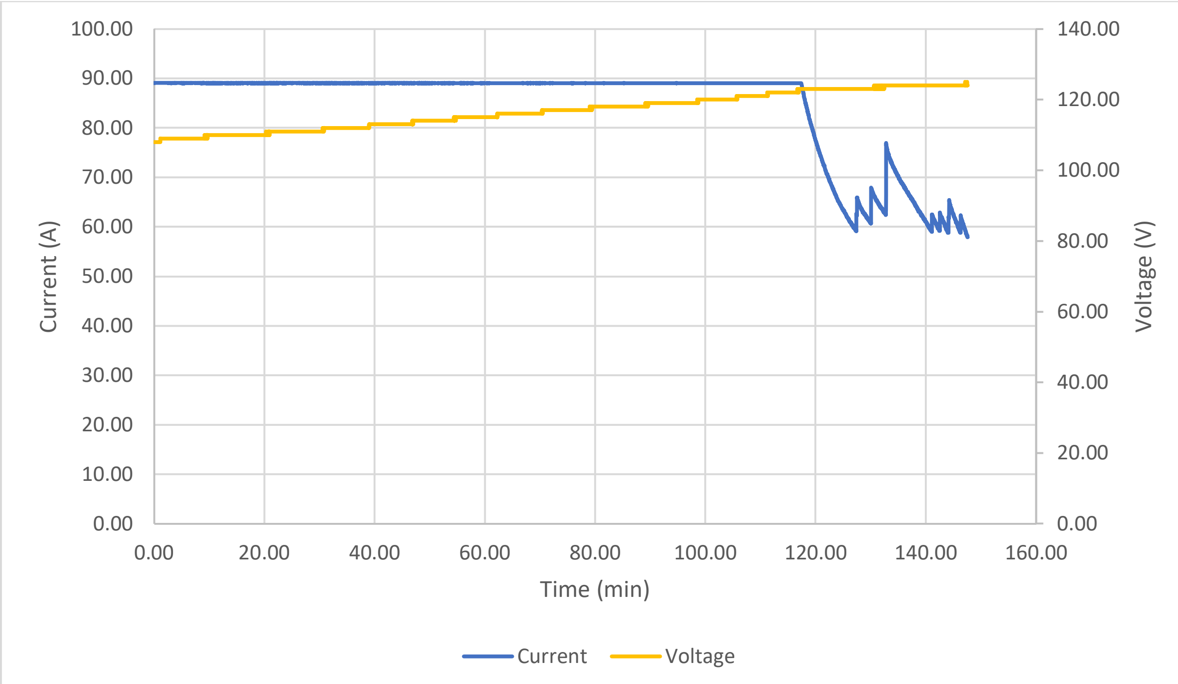


Figure A1 – Charge Profile for Initiating Module

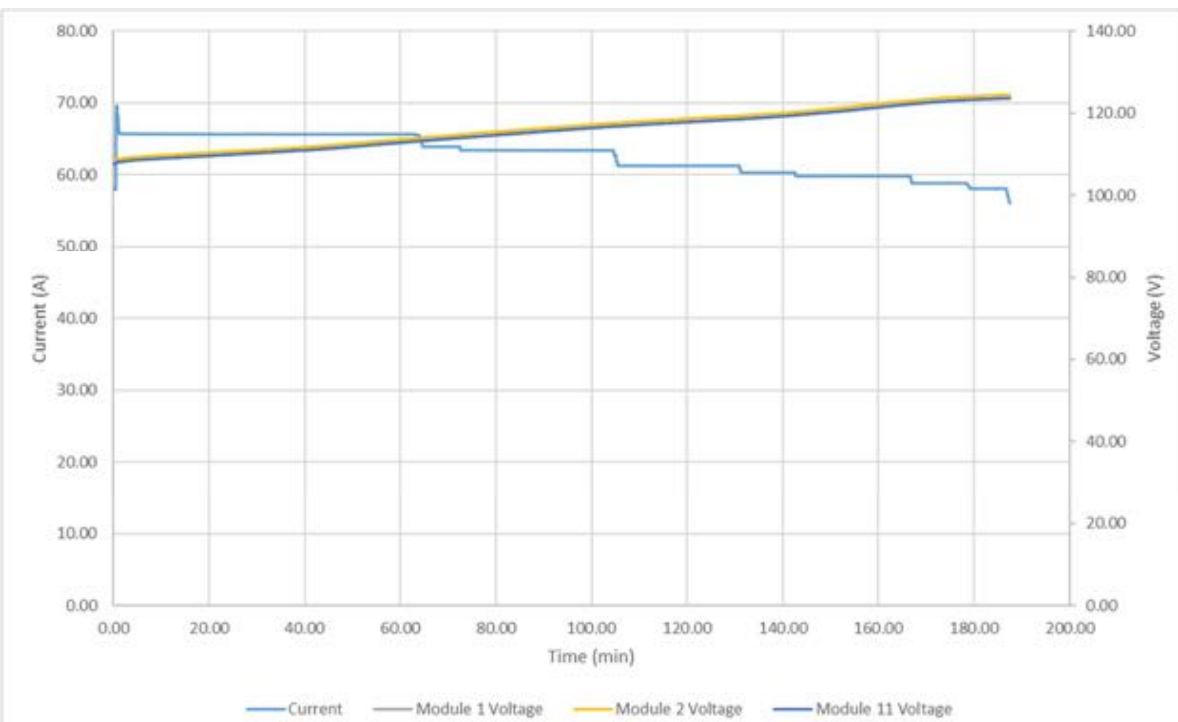


Figure A2 – Charge Profile for Modules 1, 2 and 11

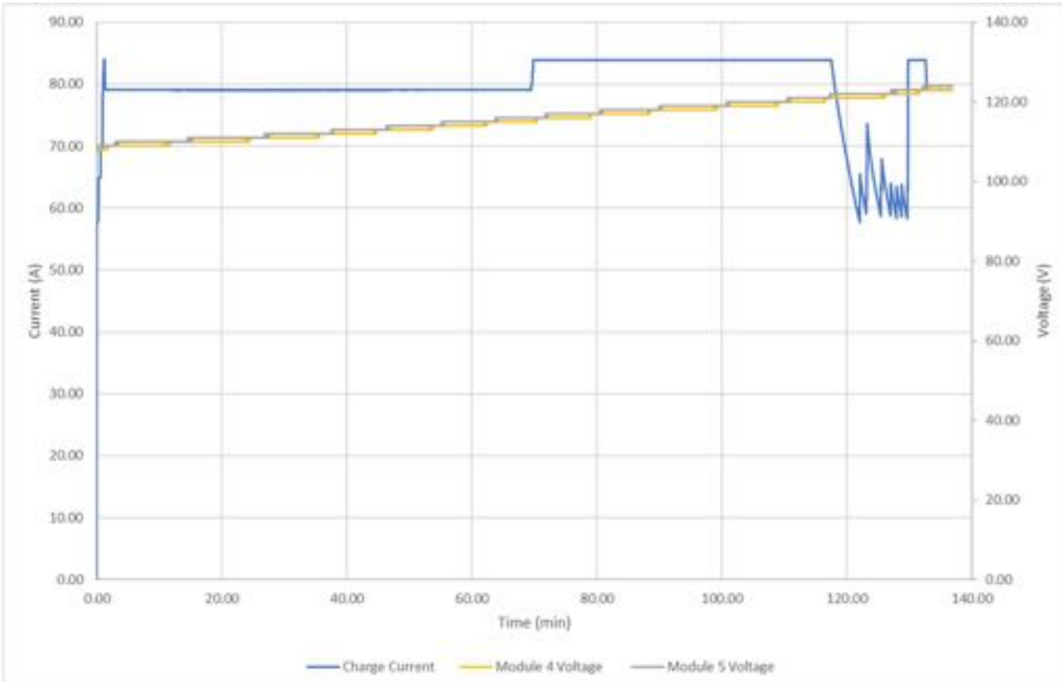


Figure A3 – First Charge Profile for Modules 4 and 5

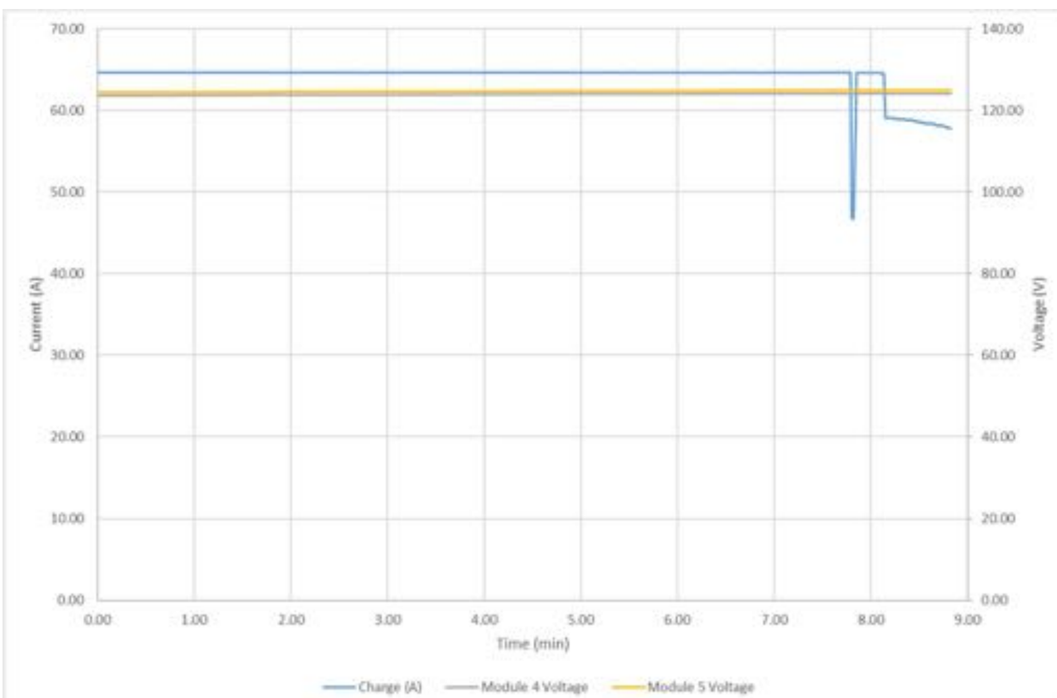


Figure A4 – Second Charge Profile for Modules 4 and 5

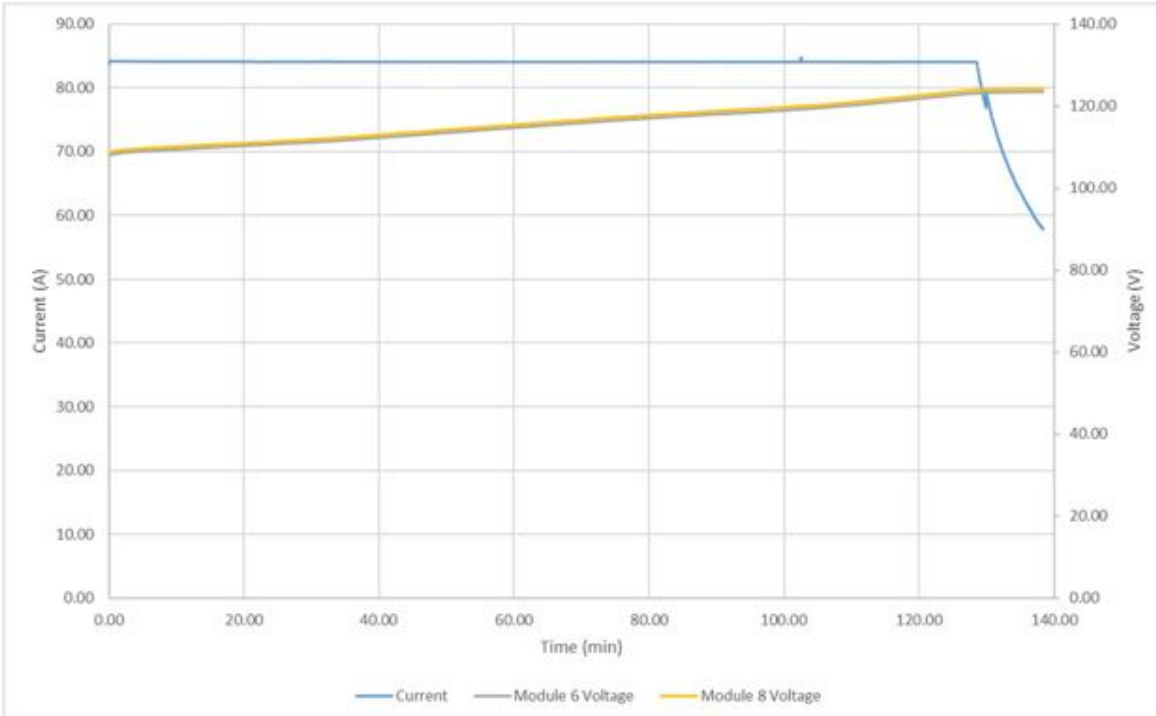


Figure A5 – Charge Profile for Modules 6 and 8

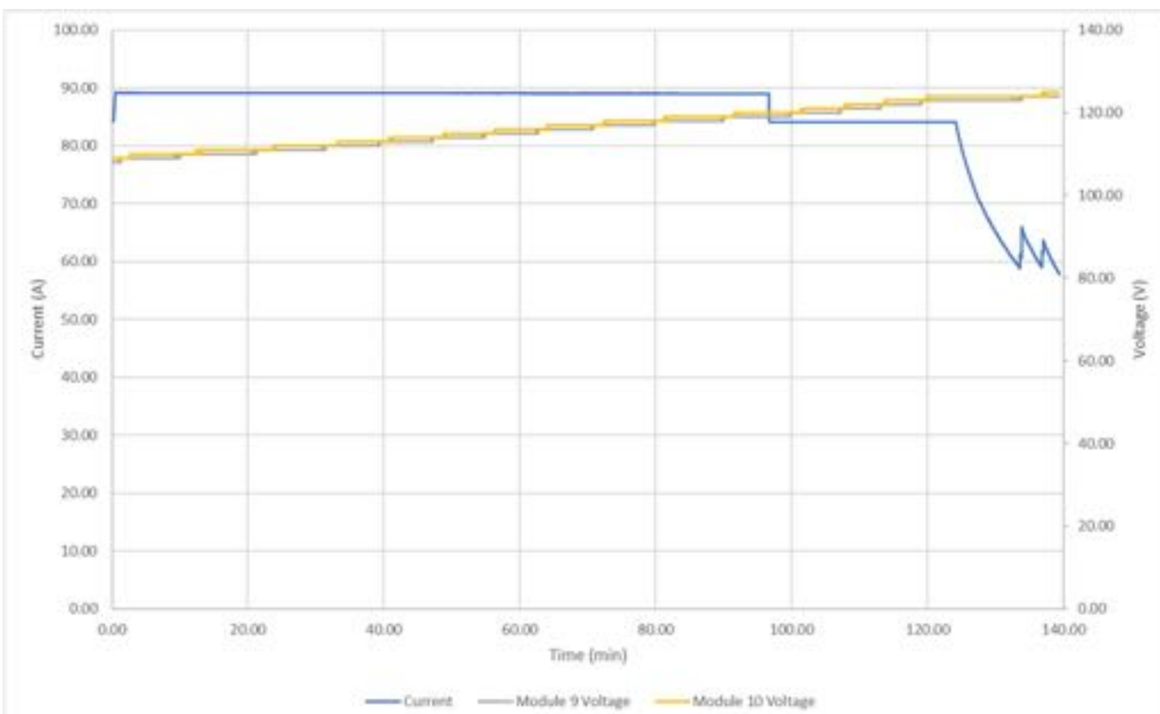


Figure A6 – Charge Profile for Modules 9 and 10

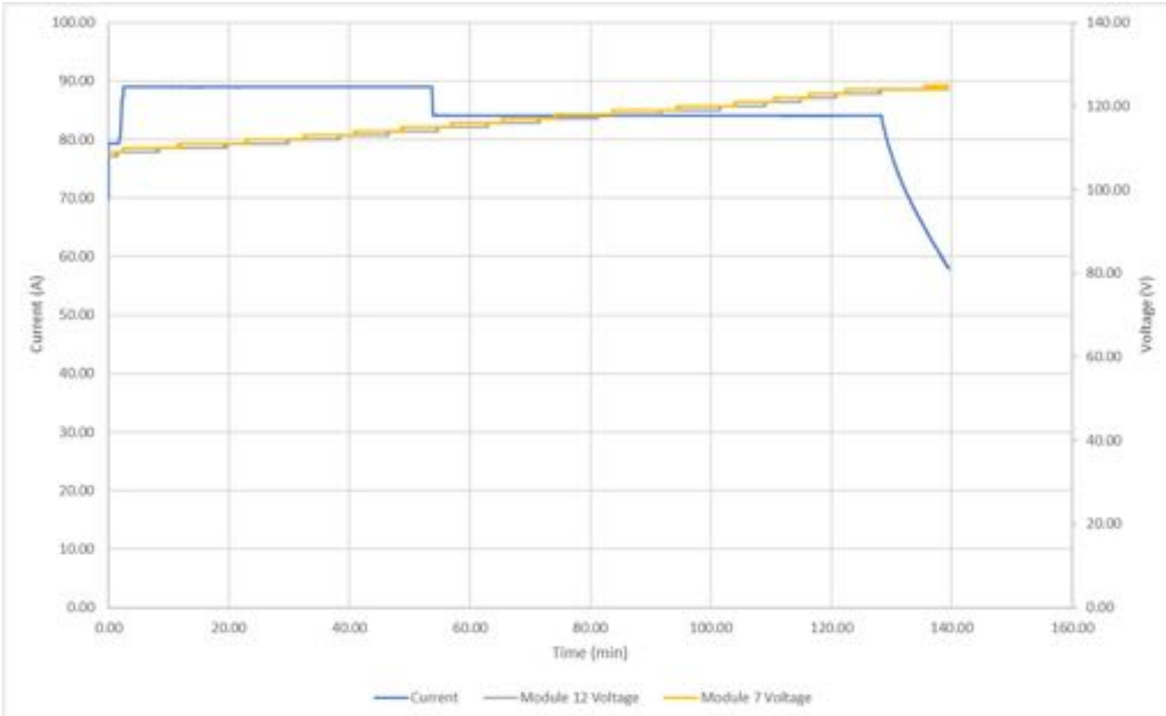


Figure A7 – Charge Profile for Modules 7 and 12

Attachment B: BESS (including module and any integral fire detection and suppression systems) Construction Photos/Diagrams - (*Pages **29** through **32***)

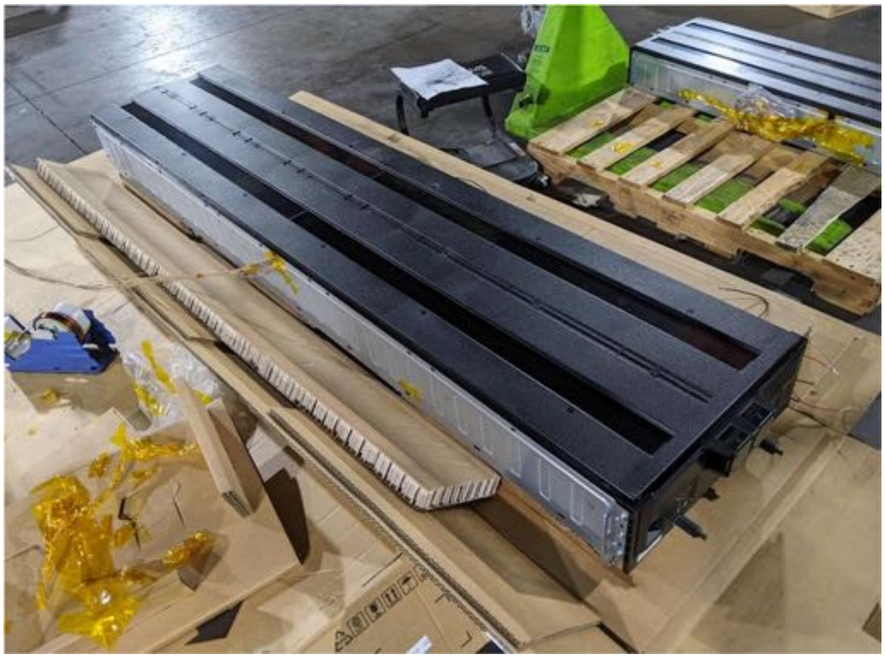


Figure B1 – Overall view of the Initiating Module

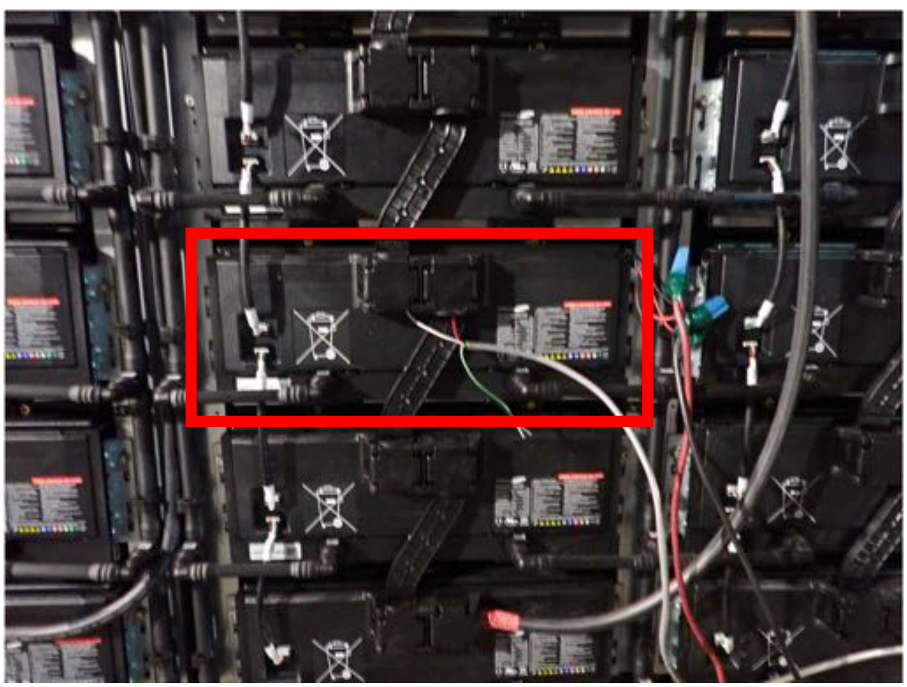


Figure B2 – Front view of the Initiating Module in the Initiating Unit (The third module from the bottom)

Figure B3 – Overall View of the Initiating and Target Units

Figure B4 – Smoke Detectors Located on Top of Units

Figure B5 – Fire Panel System – Connected to the NOVEC Release System

Figure B6 –NOVEC cylinder with Connected pressure transducer and flow meter– only one cylinder was used and the other cylinder near the wall was a spare cylinder.

Figure B7 – Dummy Racks with NOVEC Piping[6]

[6] The dummy racks were used to simulate a potential pressure drop expected in the field. As more racks can be installed in the field, which could cause a pressure drop. The dummy rack was designed and provided by Samsung SDI.

Attachment C: : BESS and Equipment Instrumentation and Test Installation Layout Photos/Diagrams - (*Pages **33** through **41***)

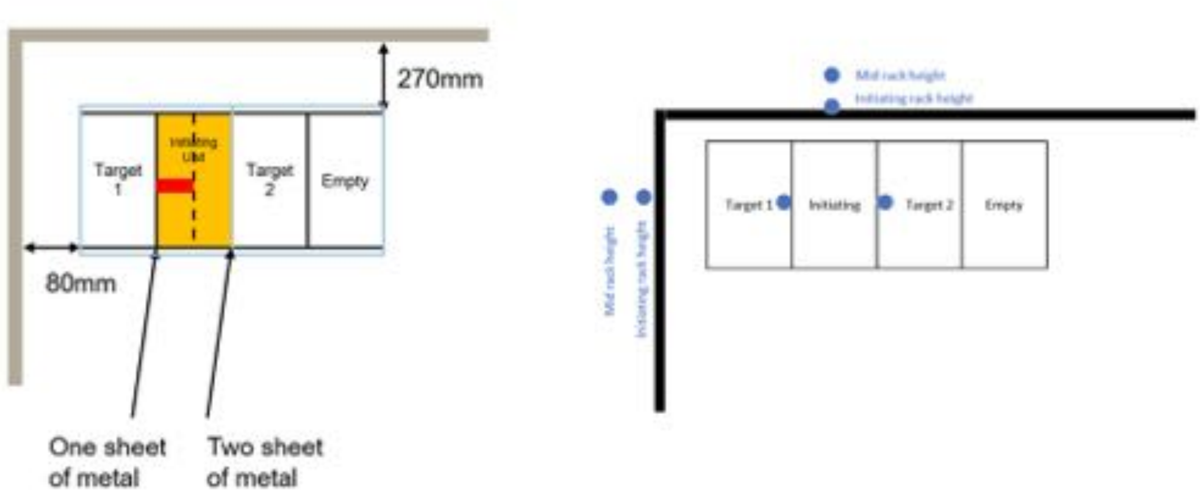
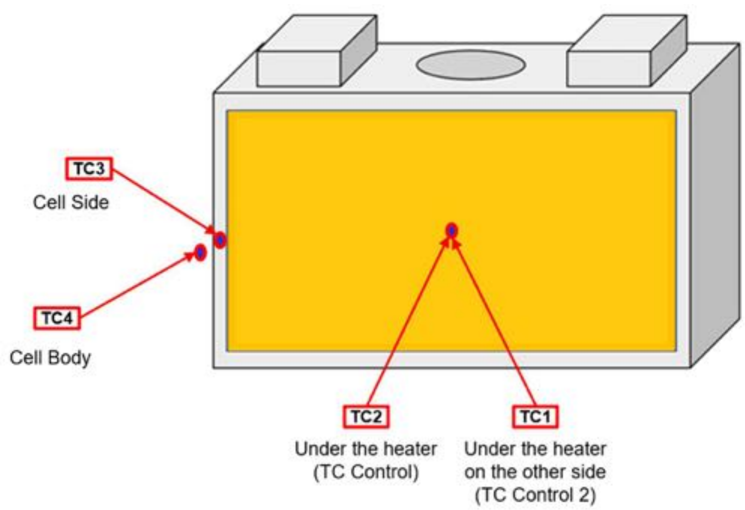
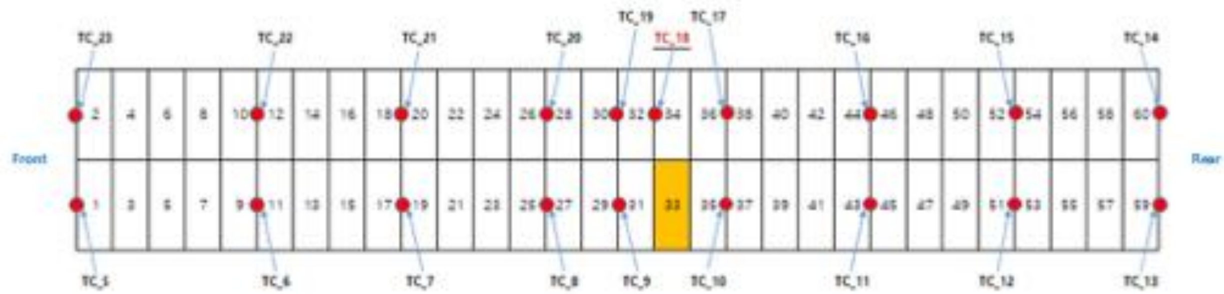


Figure C1 – Unit Configuration and Heat Flux Gauge Plan – Blue dots represent heat flux gauges installed in the instrumented walls and target units.



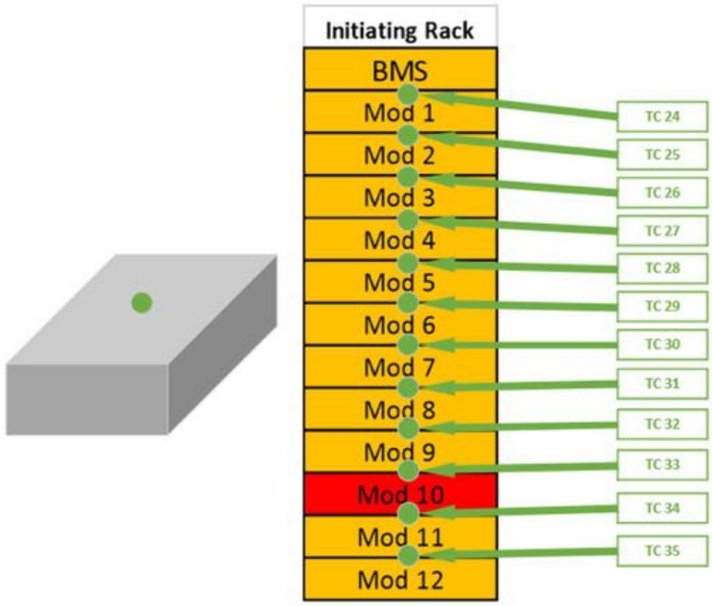
Thermocouple #	Description of Thermocouple Location
1	Heater Control – Located under the heater
2	Backup to Heater Control
3	Cell Side – Adjacent to the heater
4	Cell Body – On the surface perpendicular to the heated surface

Figure C2 – Thermocouple Locations and Descriptions for the Initiating Cell



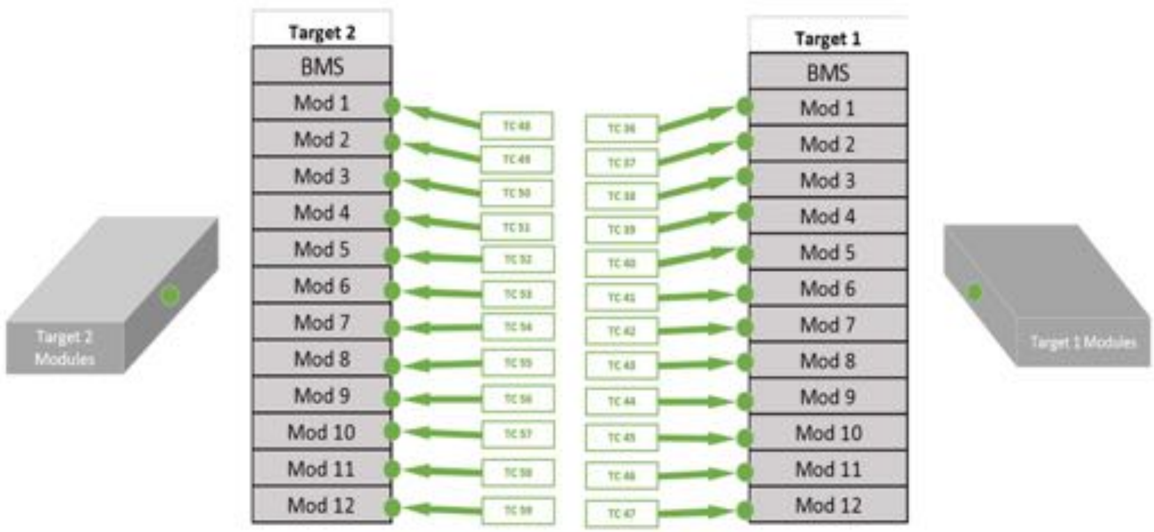
Thermocouple #	Description of Thermocouple Location
5	Cell 1
6	Cell 11
7	Cell 19
8	Cell 27
9	Cell 31
10	Cell 35
11	Cell 43
12	Cell 51
13	Cell 59
14	Cell 60
15	Cell 52
16	Cell 44
17	Cell 36
18	Cell 34
19	Cell 32
20	Cell 28
21	Cell 20
22	Cell 12
23	Cell 2

Figure C3 – Thermocouple Locations and Descriptions for the Initiating Module



Thermocouple #	Description of Thermocouple Location
24	Initiating Unit - Module 1
25	Initiating Unit - Module 2
26	Initiating Unit - Module 3
27	Initiating Unit - Module 4
28	Initiating Unit - Module 5
29	Initiating Unit - Module 6
30	Initiating Unit - Module 7
31	Initiating Unit - Module 8
32	Initiating Unit - Module 9
33	Initiating Unit - Module 10
34	Initiating Unit - Module 11
35	Initiating Unit - Module 12

Figure C4 – Thermocouple Locations and Descriptions for the Initiating Rack



Thermocouple #	Description of Thermocouple Location	Thermocouple #	Description of Thermocouple Location
36	Target 1 - Module 1	48	Target 2 - Module 1
37	Target 1 - Module 2	49	Target 2 - Module 2
38	Target 1 - Module 3	50	Target 2 - Module 3
39	Target 1 - Module 4	51	Target 2 - Module 4
40	Target 1 - Module 5	52	Target 2 - Module 5
41	Target 1 - Module 6	53	Target 2 - Module 6
42	Target 1 - Module 7	54	Target 2 - Module 7
43	Target 1 - Module 8	55	Target 2 - Module 8
44	Target 1 - Module 9	56	Target 2 - Module 9
45	Target 1 - Module 10	57	Target 2 - Module 10
46	Target 1 - Module 11	58	Target 2 - Module 11
47	Target 1 - Module 12	59	Target 2 - Module 12

Figure C5 – Thermocouple Locations and Descriptions for Target Units

Table C1 – Thermocouple Locations on Instrumented Walls

Thermocouple #	Description of Thermocouple Location	Thermocouple #	Description of Thermocouple Location
60	Front Wall - 6 inches	83	Side Wall - 6 inches
61	Front Wall - 12 inches	84	Side Wall - 12 inches
62	Front Wall - 18 inches	85	Side Wall - 18 inches
63	Front Wall - 24 inches	86	Side Wall - 24 inches
64	Front Wall - 30 inches	87	Side Wall - 30 inches
65	Front Wall - 36 inches	88	Side Wall - 36 inches
66	Front Wall - 42 inches	89	Side Wall - 42 inches
67	Front Wall - 48 inches	90	Side Wall - 48 inches
68	Front Wall - 54 inches	91	Side Wall - 54 inches
69	Front Wall - 60 inches	92	Side Wall - 60 inches
70	Front Wall - 66 inches	93	Side Wall - 66 inches
71	Front Wall - 72 inches	94	Side Wall - 72 inches
72	Front Wall - 78 inches	95	Side Wall - 78 inches
73	Front Wall - 84 inches	96	Side Wall - 84 inches
74	Front Wall - 90 inches	97	Side Wall - 90 inches
75	Front Wall - 96 inches	98	Side Wall - 96 inches
76	Front Wall - 102 inches	99	Side Wall - 102 inches
77	Front Wall - 108 inches	100	Side Wall - 108 inches
78	Front Wall - 114 inches	101	Side Wall - 114 inches
79	Front Wall - 120 inches	102	Side Wall - 120 inches
80	Front Wall - 126 inches	103	Side Wall - 126 inches
81	Front Wall - 132 inches	104	Side Wall - 132 inches
82	Front Wall - 138 inches	105	Side Wall - 138 inches

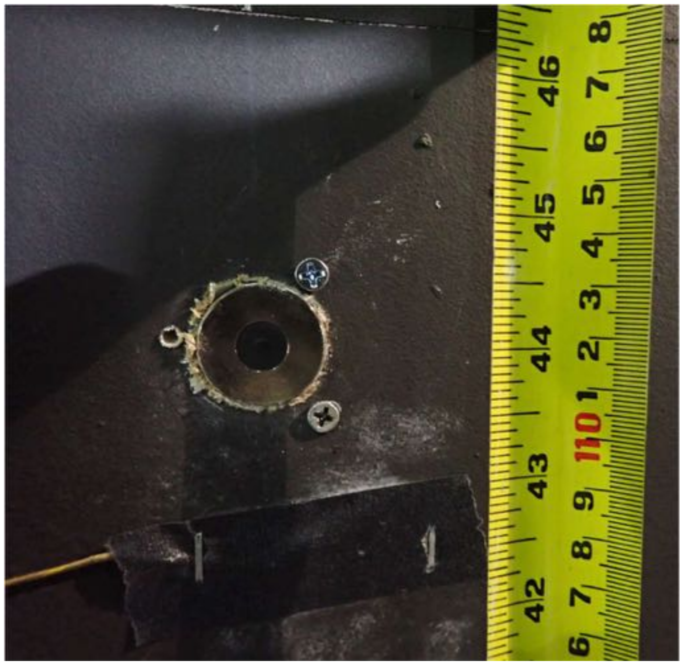


Figure C6 – Heat Flux Installed in the Front Wall at Mid-Unit Height

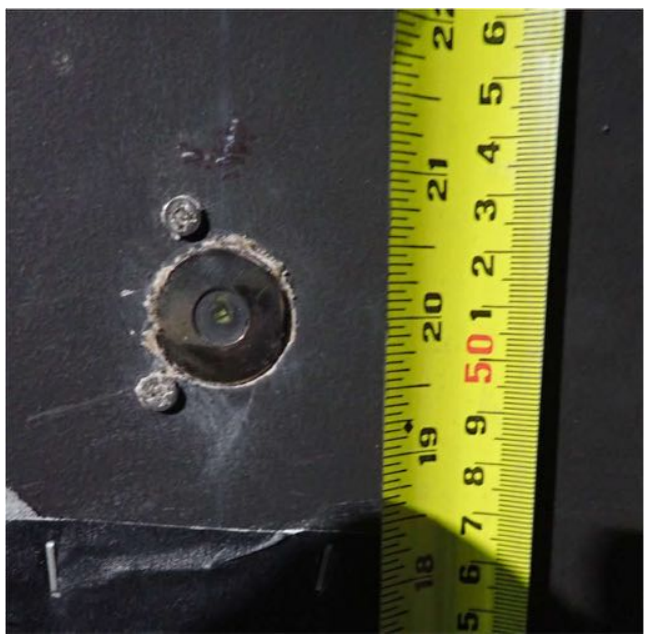


Figure C7 – Heat Flux Installed in the Front Wall at Initiating Module Height

Figure C8 – Heat Flux in Front Wall Centered with Initiating Unit

Figure C9 – Heat Flux Heat Flux Installed in the Side Wall at Mid-Unit Height

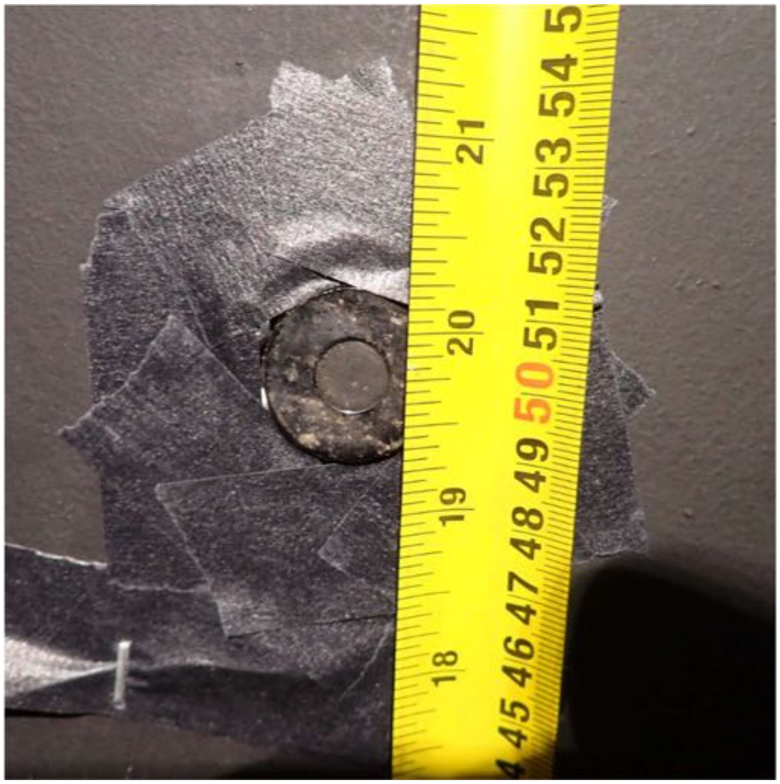


Figure C10 - Heat Flux Installed in the Side Wall at Initiating Module Height

Figure C11 – Heat Flux Installed in the Target Units

Figure C12 – Distance from Side Wall to Target Unit 2

Figure C13 – Distance from Front Wall to Rear of Units

Attachment D: Temperature Profiles and Heat Flux Measurements During Testing (Initiating Cell and Module, Target Modules, Wall Surfaces, etc. - (*Pages **42** through **46***)

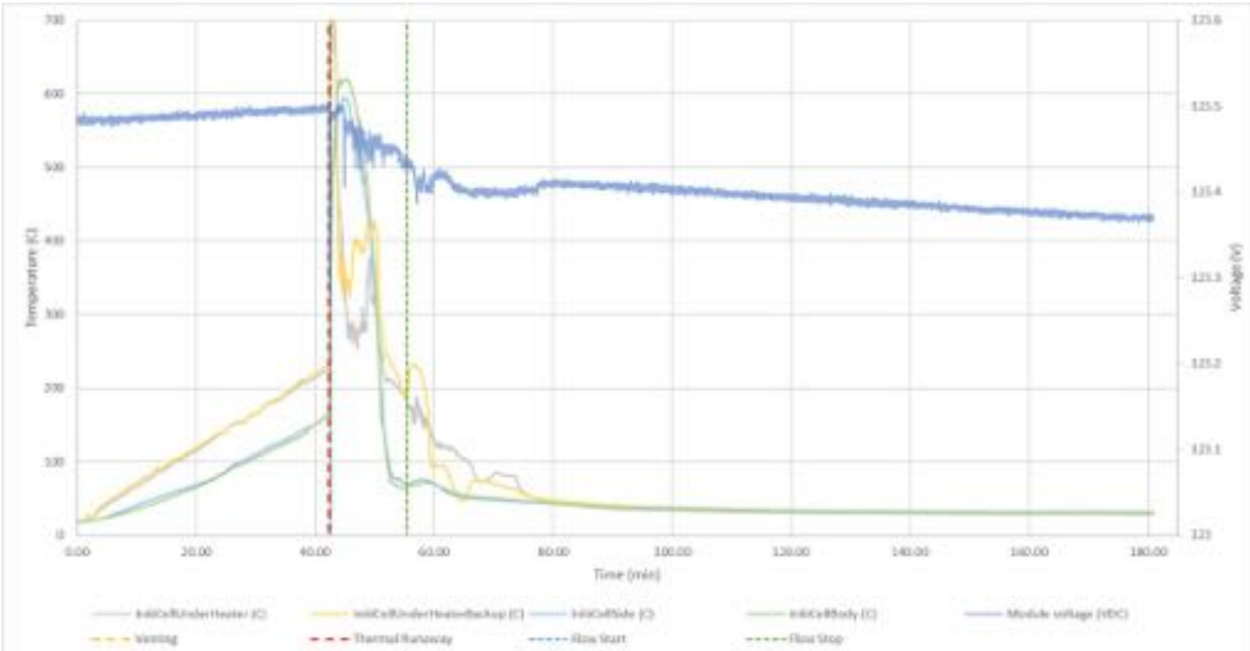


Figure D1 – Temperature Profiles for Initiating Cell (Cell 33)

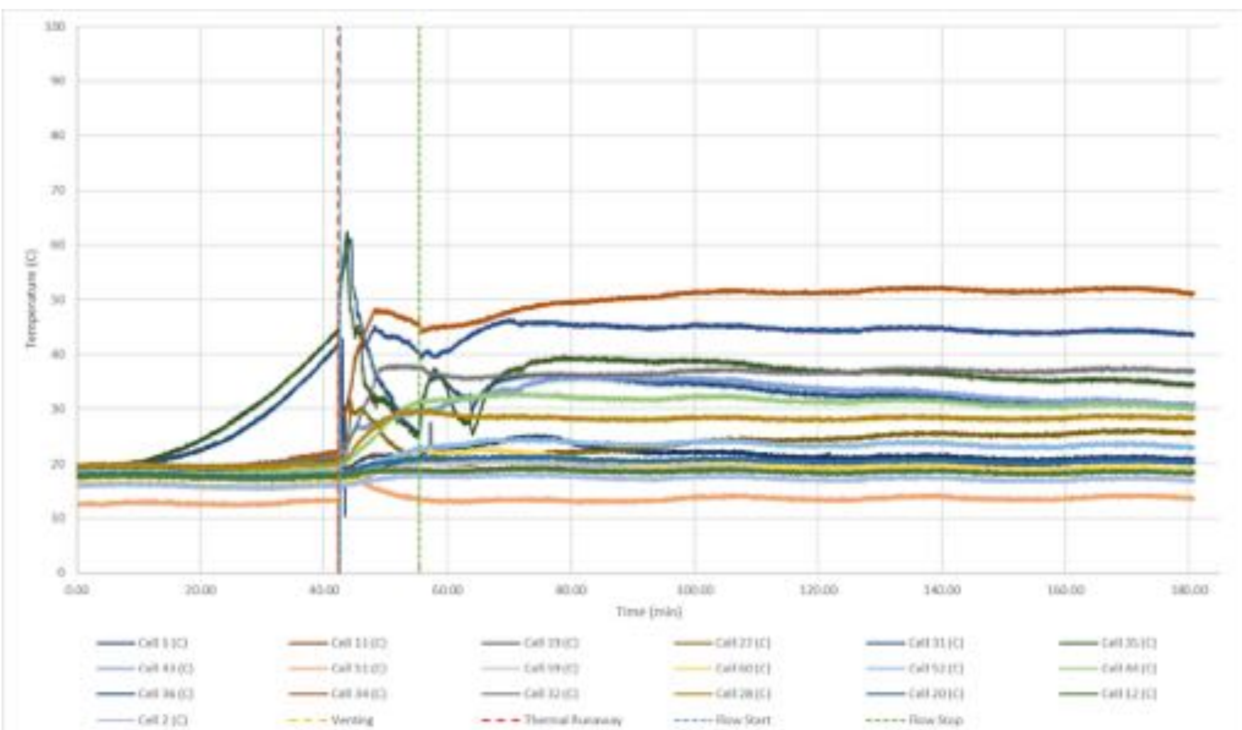


Figure D2 – Temperature Profiles for Non-Initiating Cells

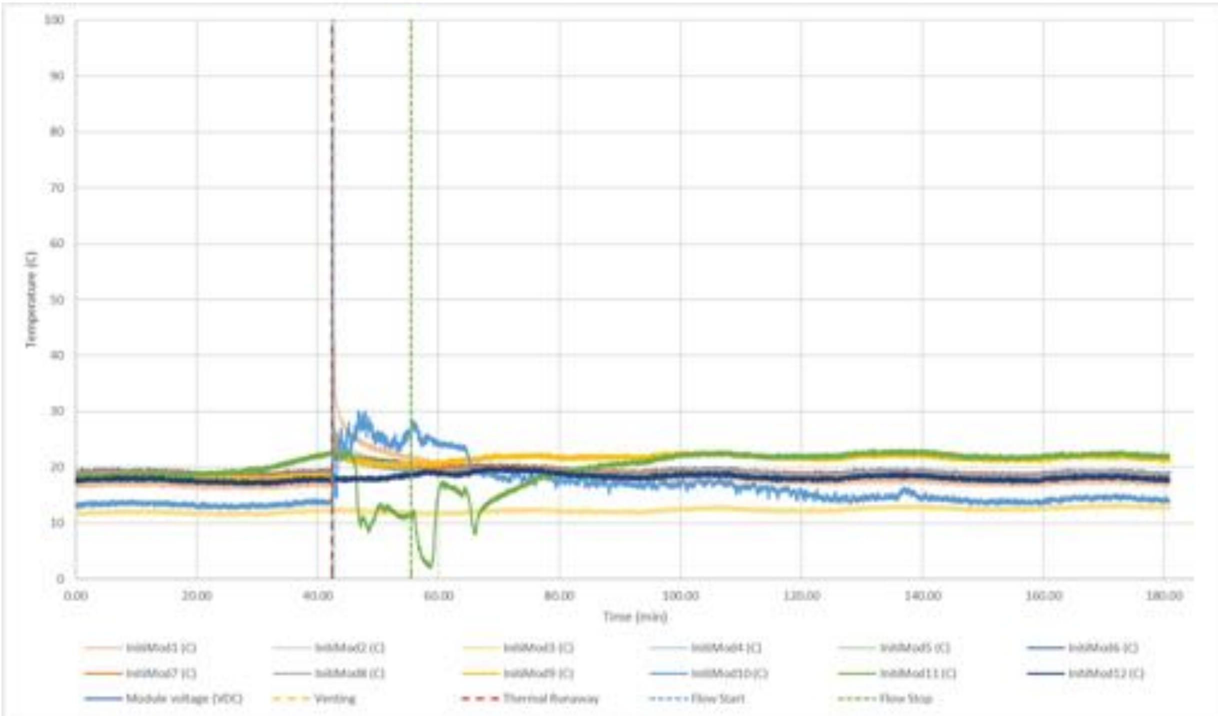


Figure D3 – Temperature Profiles for Modules in the Initiating Module

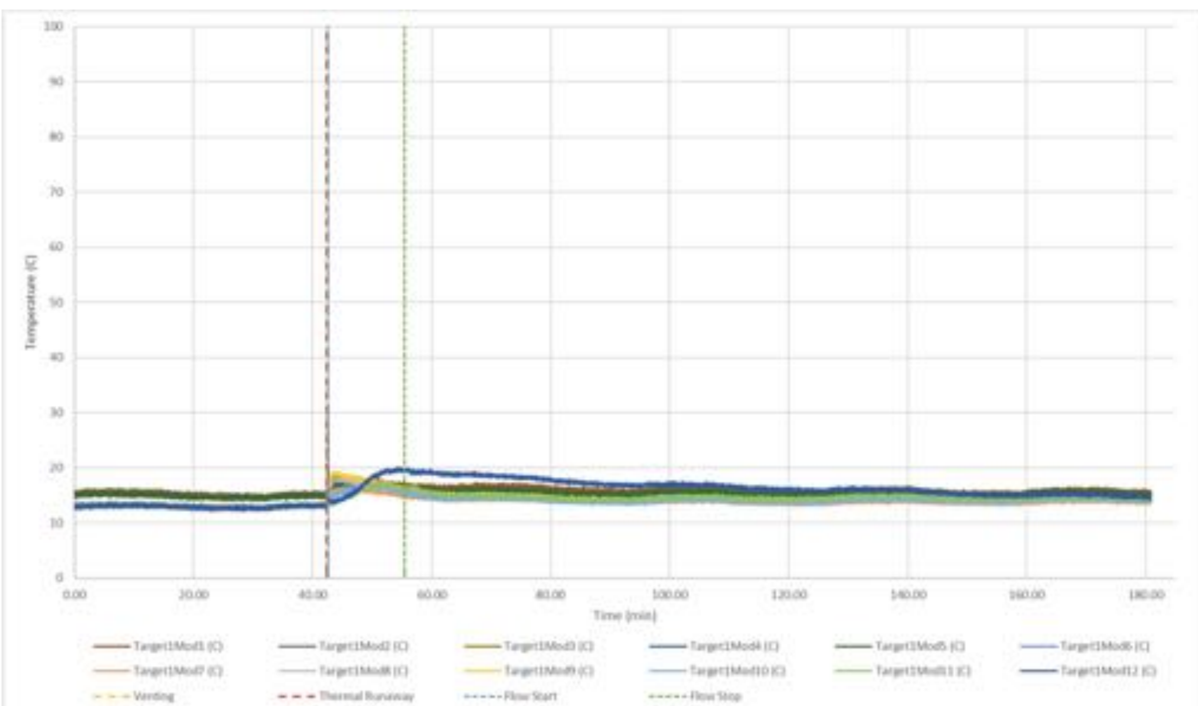


Figure D4 – Temperature Profiles for Modules in Target Unit 1

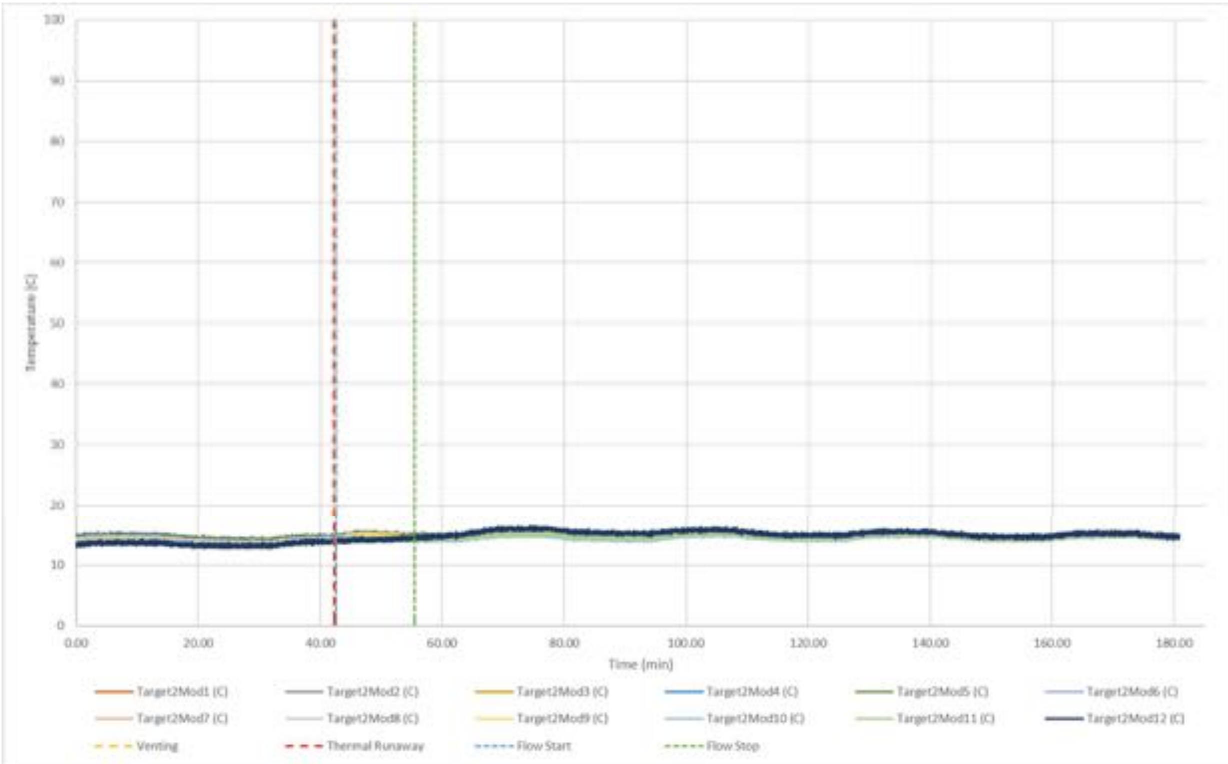


Figure D5 – Temperature Profiles for Modules in Target Unit 2

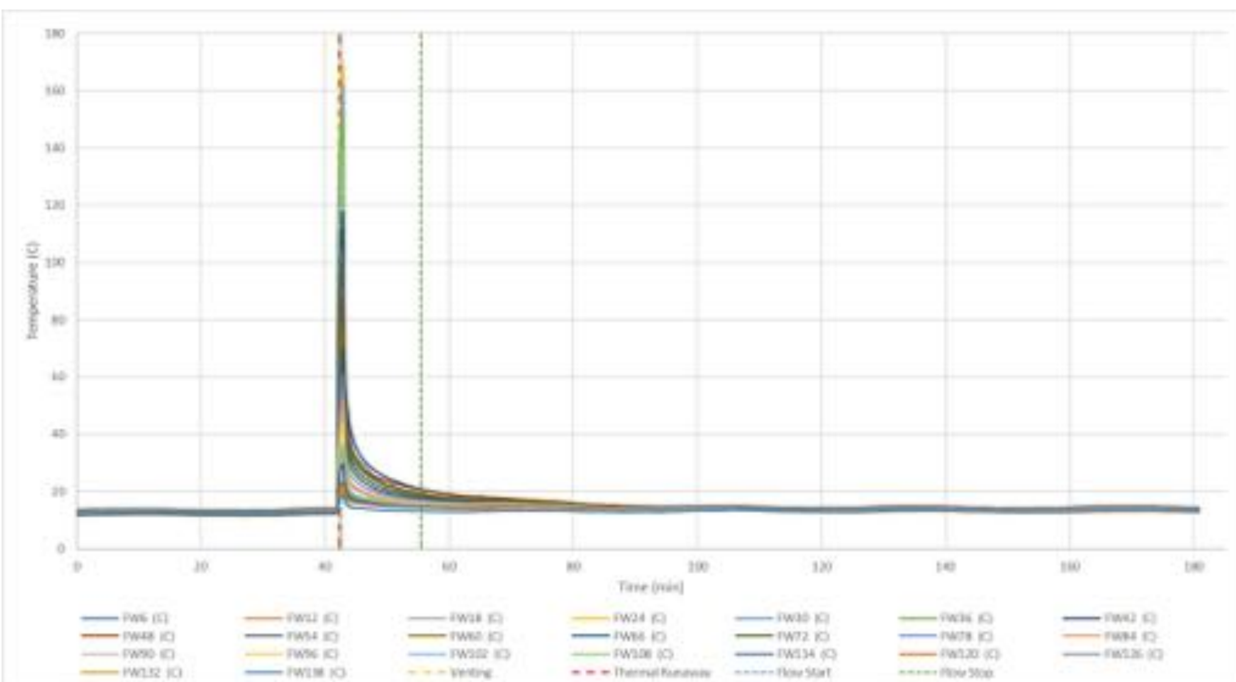


Figure D6 – Temperature Profiles for the Front Wall

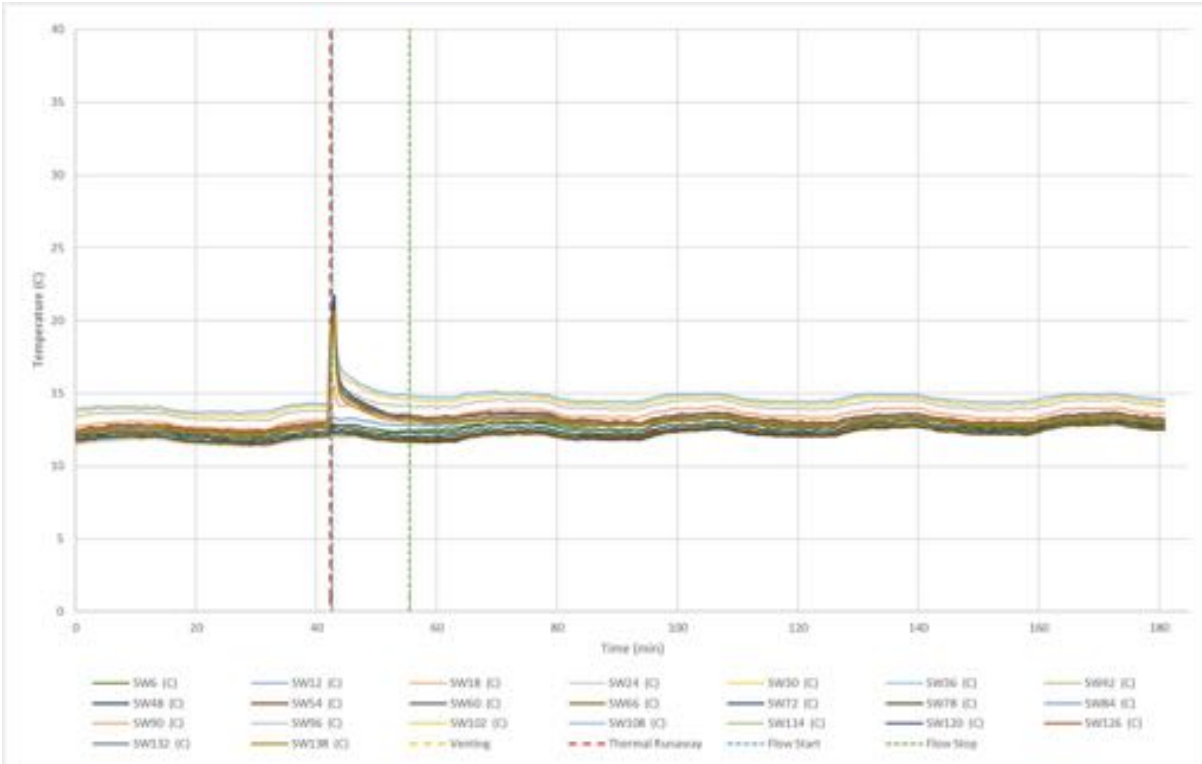


Figure D7 – Temperature Profiles for the Side Wall

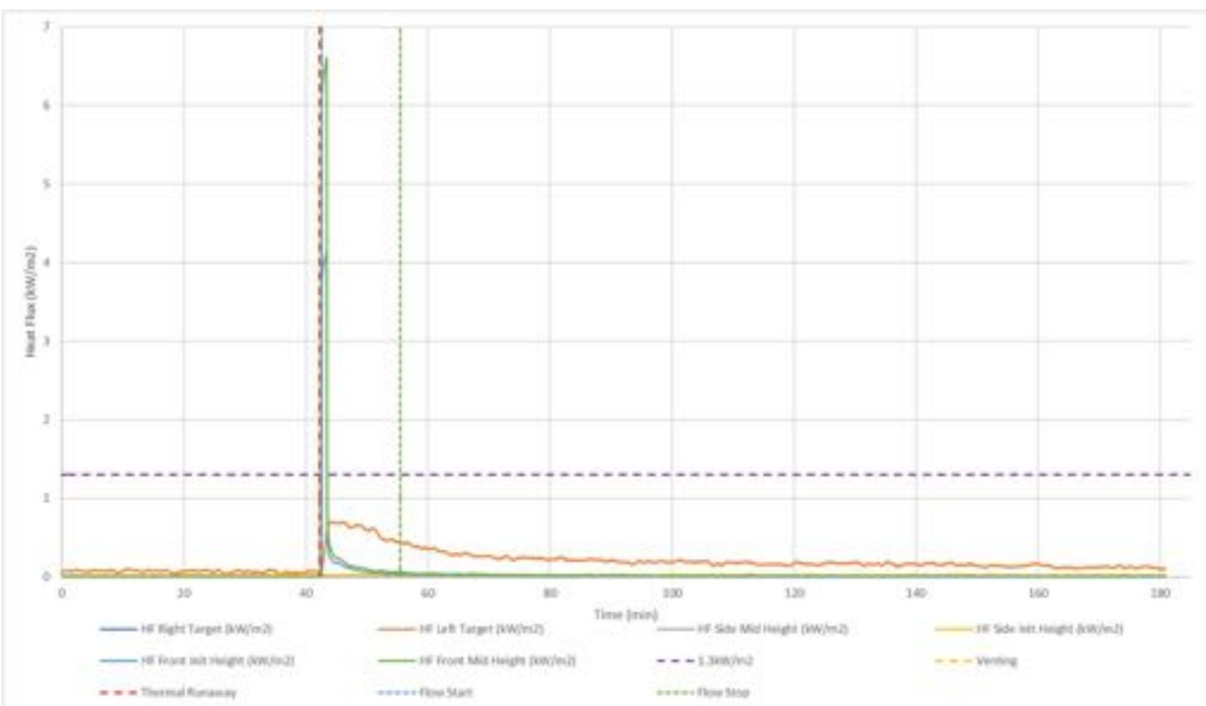


Figure D8 – Heat Flux Measurements during the Unit Test

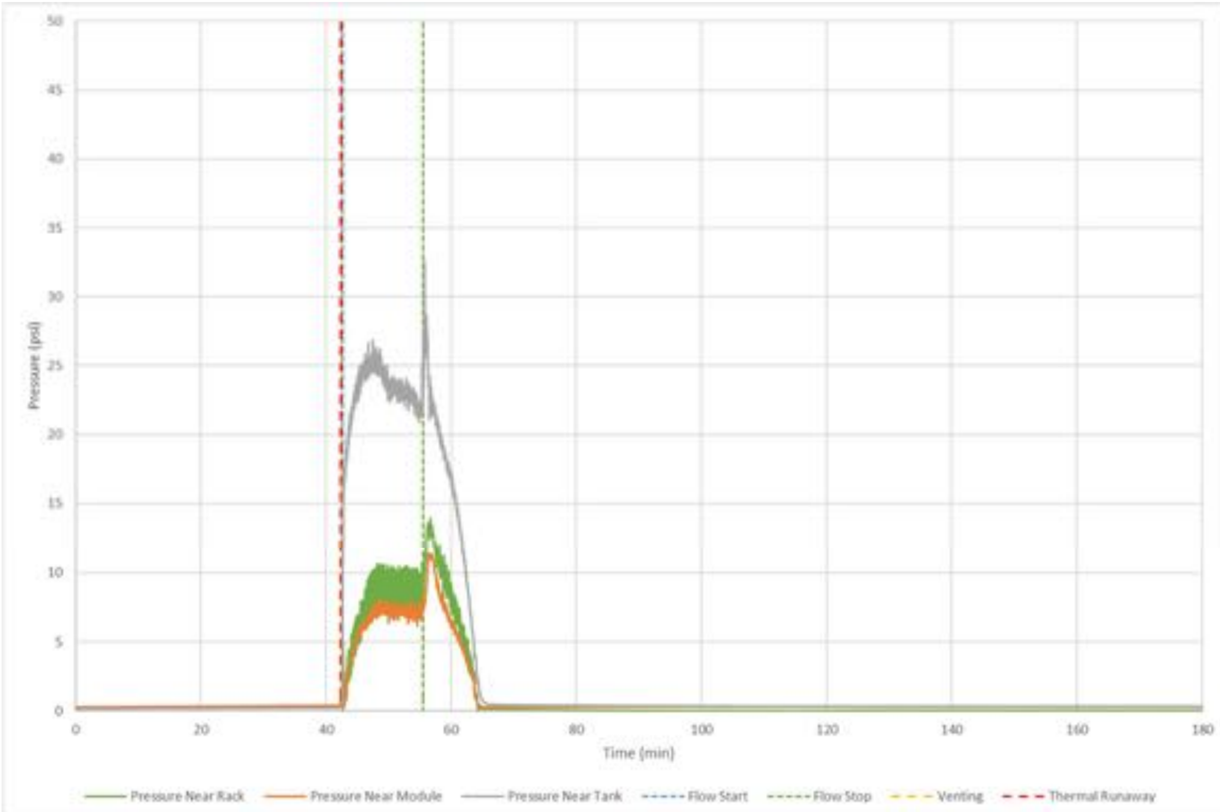
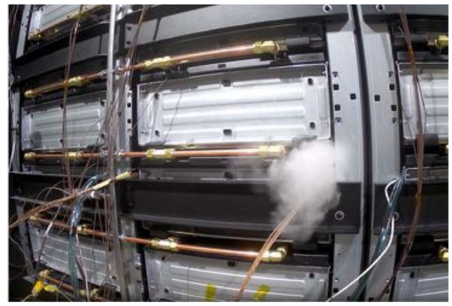
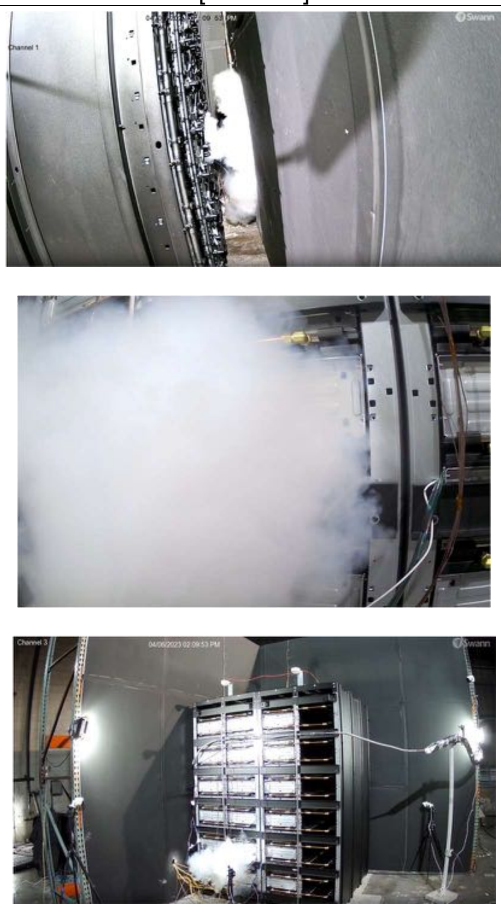
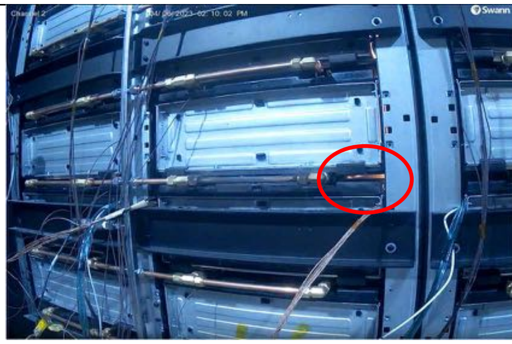
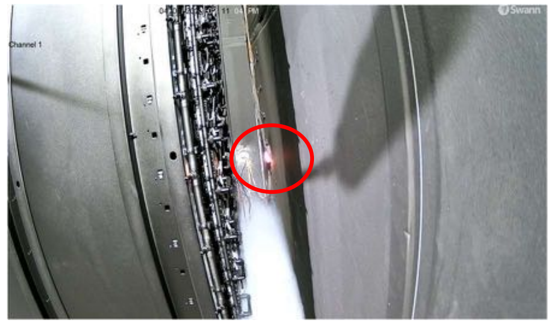
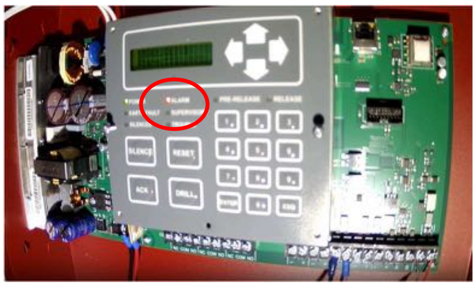
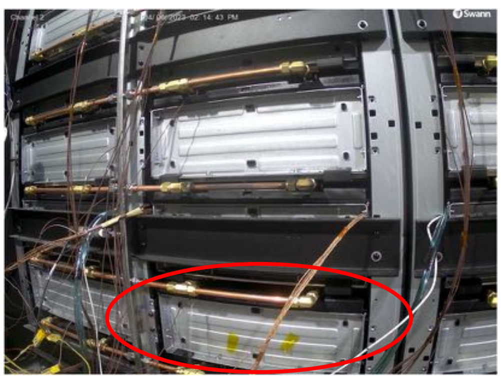


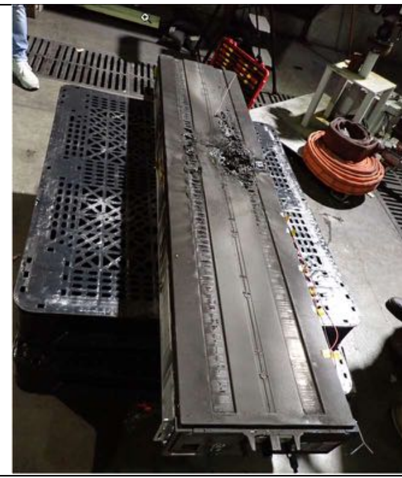
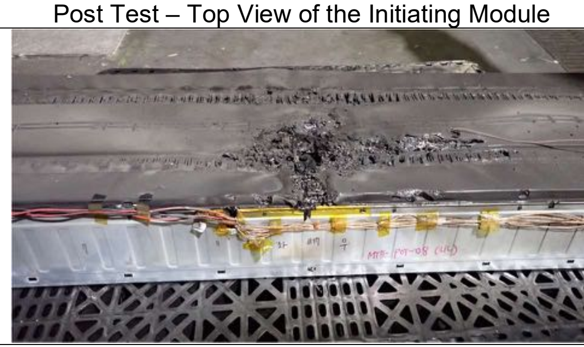
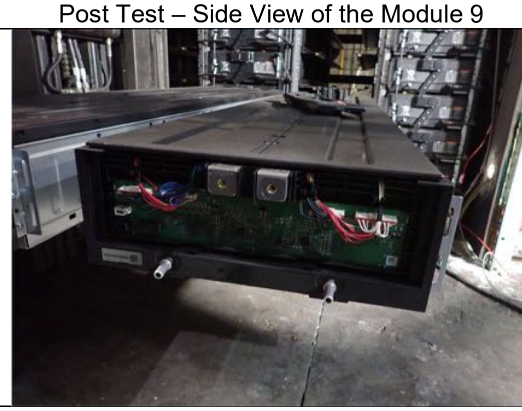
Figure D9 – Pressure Profiles for the NOVEC Tank, Initiating Module, and Rack

Attachment E: BESS Unit Testing and Post Testing Photos - (*Pages* ***47*** *through* ***50***)

 (a) Test Start [00:00:00]	 (b) Initiating Unit Vent [00:42:17]
 (c) Initiating Unit Thermal Runaway [00:42:25]	 (d) Ignition [00:42:30]

 (e) Two Seconds after Ignition – Flaming was only observed above the Initiating Module [00:42:32 – 00:42:41[7]]	 (f) External Flaming on the Camera [00:42:30 – 00:47:39]
 (g) Smoke Detection – Alarm LED Turns On[8] [00:42:29]	 (h) NOVEC Release [00:42:30]
 (i) NOVEC Flowing Over on the top of the module below the initiating module [00:54:42 – 01:08:23]	 (j) Test End [03:00:51]

[7] The end of the flame was visually analysed based on the video taken at the back of the module
[8] The system would release NOVEC based on signals from two different smoke detectors, however, based on the video analysis, which was the only analysis available to identify the time of smoke detection, it was not inconclusive to pinpoint the second smoke detector sending the signal.

	
Post Test – Front View of the Initiating Unit	Post Test – Top View of the Initiating Module
	
Post Test – Rear View of the Initiating Module	Post Test – Side View of the Initiating Module
	
Post Test – View of the NOVEC Piping	Post Test – Side View of the Module 9
	
Post Test – Front Cover of Module 9	Post Test – Front View of Module 9

	
Post Test – Front View of Module 11	Post Test – Top View of Module 11

Attachment F: BESS Unit Gas Flow Rate and Heat Release and Smoke Release Profiles - (*Pages **51** through **54***)

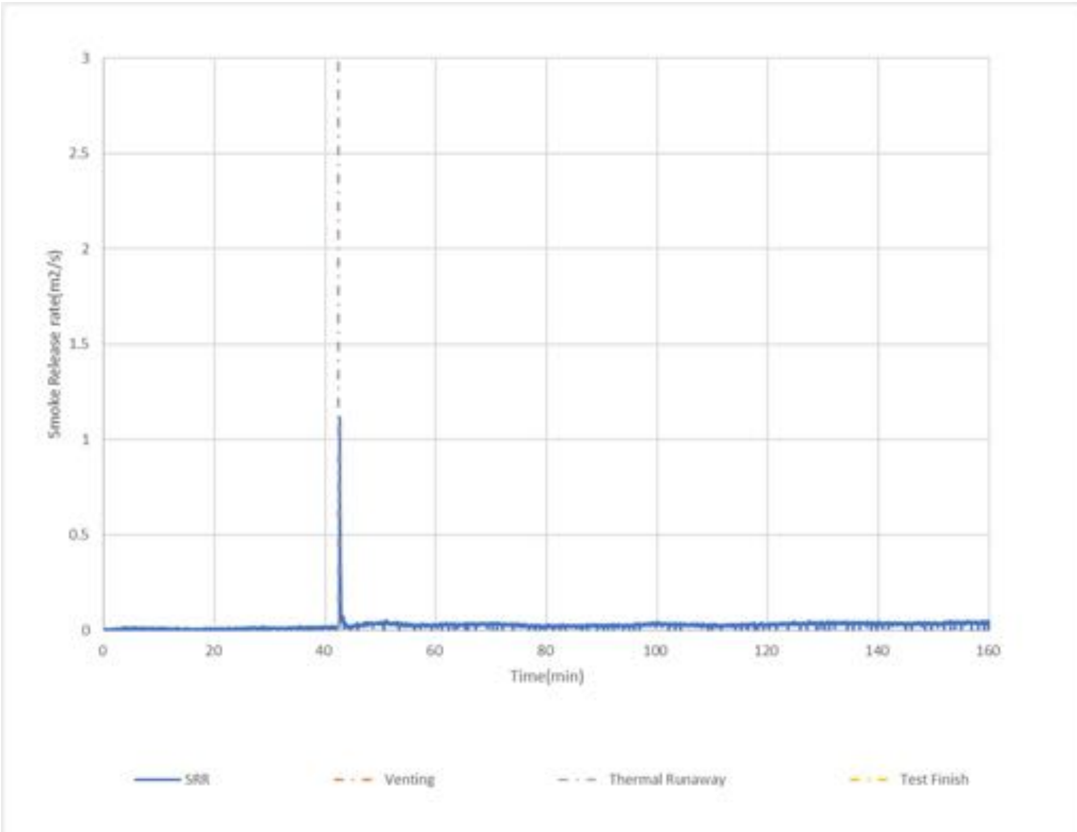


Figure G1 – Smoke Release Rate during the Unit Level Test

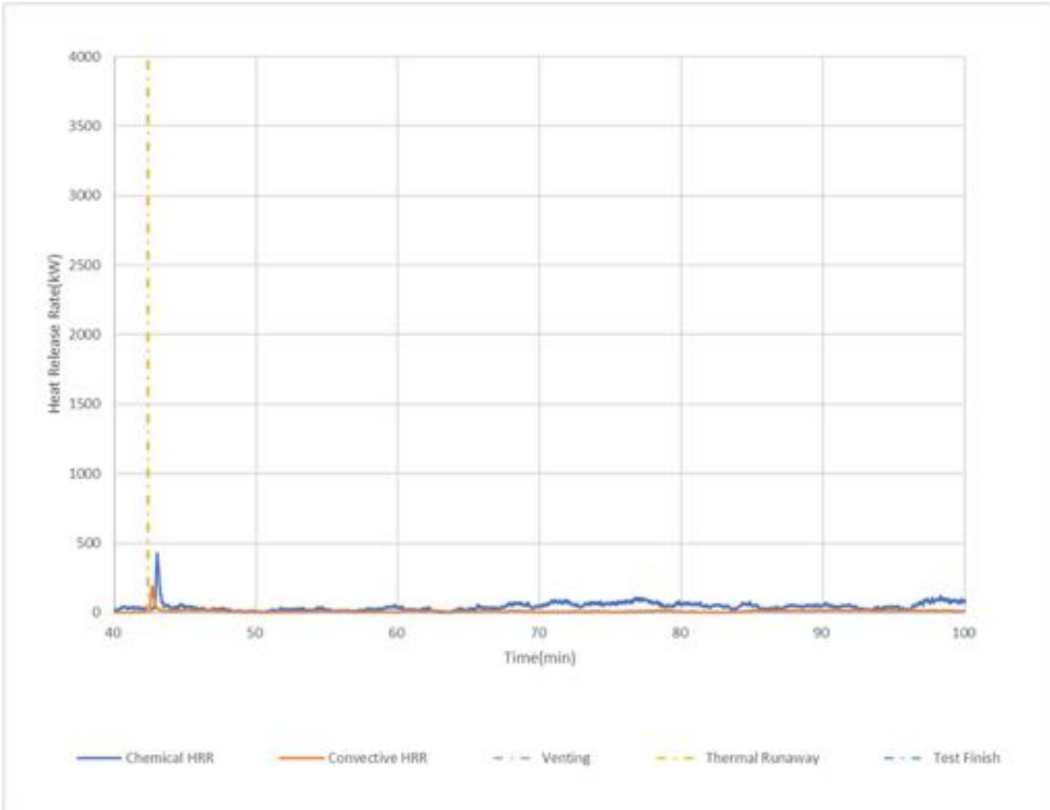


Figure G2 – Heat Release Rate during the Unit Level Test[9]

[9] No fire was observed after flame from the thermal runaway was extinguished. The increase of heat release rate around 70 minutes into the test is assumed to be due to the moisture and the depletion of oxygen coming from NOVEC released

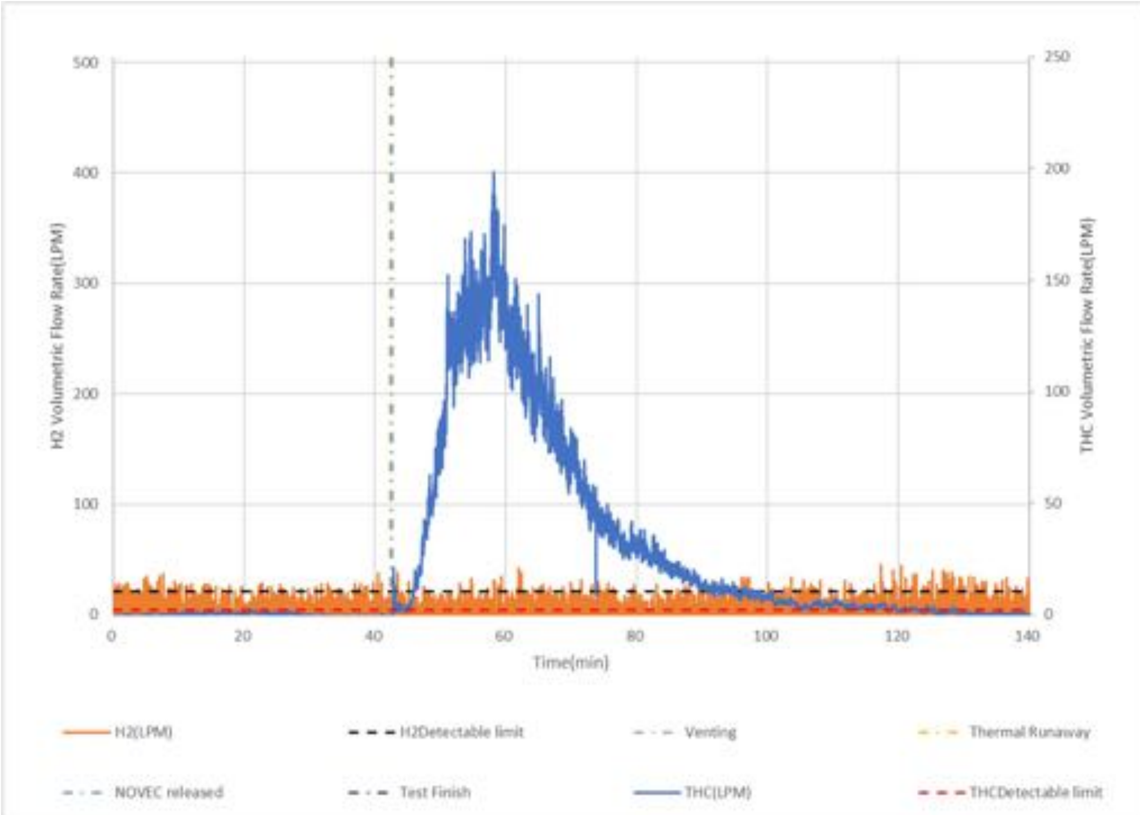


Figure G3 – H2[10] and THC[11] Volumetric Flow Rate during Unit Level Test

[10] The noise exceeded the minimum detectable limit intermittently, however, the concentration of H2 measured during the test confirmed that no hydrogen was measured during the test.
[11] The increase of THC is due to NOVEC released from the system as the THC was analyzed with FID.

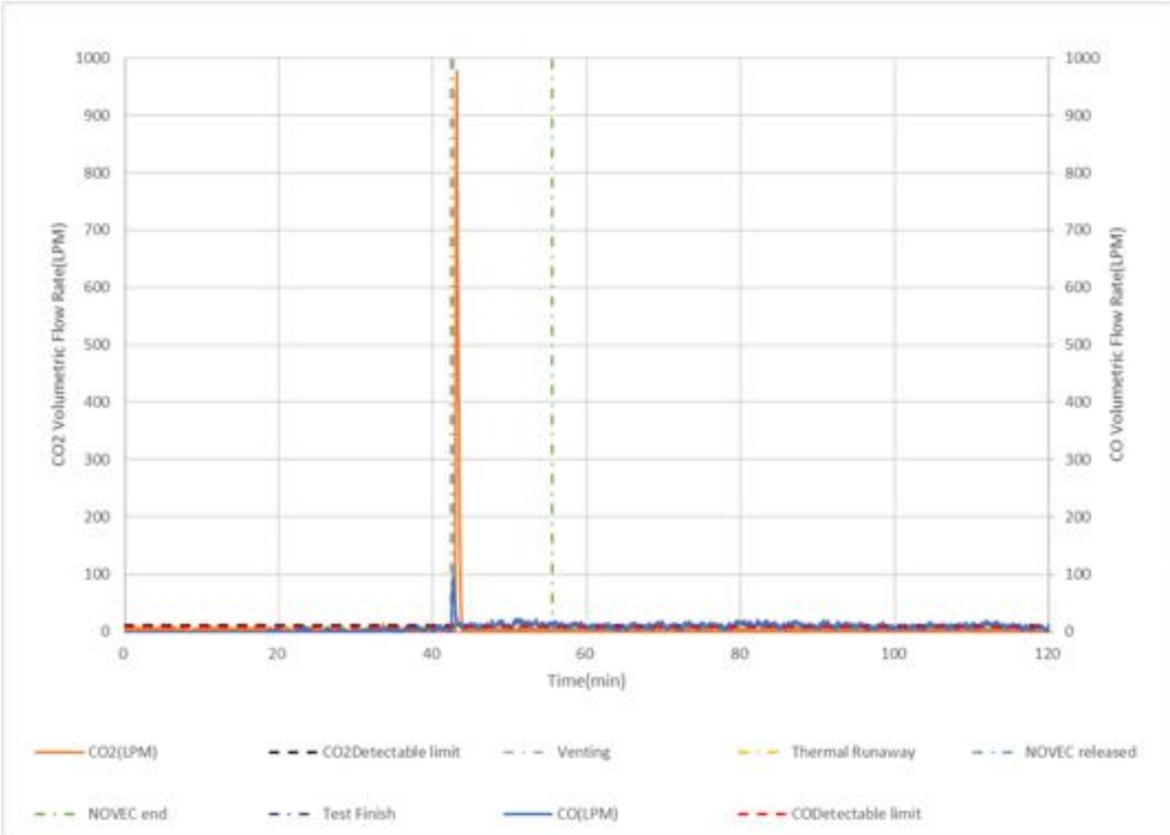


Figure G4 – CO and CO2 Volumetric Flow Rate during Unit Level Test

Attachment G: Certification Requirement Decision - (*Pages **55** through **56***)

CRD dated 2020-01-10 regarding the omission of FTIR provided below of for reference.

UNDERWRITERS LABORATORIES INC. CERTIFICATION REQUIREMENT DECISION

This Certification Requirement Decision is prepared by UL LLC. It is normative for the applicable UL Product Certification Program(s); however, it is currently not part of the UL Standard(s) referenced below.

Product Category (CCN): AACD
Standard Number: UL 9540A
Standard Title: Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems
Edition Date: November 12, 2019
Edition Number: 4
Section / Paragraph Reference: 8.12, 8.13, 9.24, 9.25, 10.3.13
Subject: Corrections to gas measurement methods to make FTIR as an option for measuring hydrocarbon contents of gas emissions and to include Hydrogen measurements during the Unit Level Test.

DECISION:

8.2.1~~3~~2 The hydrocarbon content of the vent gas shall be measured using flame ionization detection. Hydrogen gas shall be measured with a palladium-nickel thin-film solid state sensor.

8.2.1~~2~~3 The hydrocarbon components of the ~~V~~vent gas composition may additionally ~~shall~~ be measured using a Fourier-Transform Infrared Spectrometer with a minimum resolution of 1 cm-1 and a path length of at least 2 m (6.6 ft), or an equivalent gas analyzer~~,~~. ~~and v~~Velocity and temperature measurements respectively shall be obtained in the exhaust duct of the heat release rate calorimeter using equipment specified in 8.2.10.

9.2.24 The composition, velocity and temperature of the initiating BESS unit vent gases shall be measured within the calorimeter's exhaust duct as outlined in 8.2.10. The hydrocarbon content of the vent gas shall be measured using flame ionization detection. Hydrogen gas shall be measured with a palladium-nickel thin-film solid state sensor. ~~Gas composition shall be measured using a Fourier-Transform Infrared Spectrometer with a minimum resolution of 1 cm-1 and a path length of at least 2.0 m (6.6 ft), or equivalent gas analyzer.~~ Composition, velocity and temperature instrumentation shall be collocated with heat release rate calorimetry instrumentation.

9.2.25 The hydrocarbon content of the vent gas ~~shall~~ may additionally ~~also~~ be measured using ~~flame ionization detection.~~ a Fourier-Transform Infrared Spectrometer with a minimum resolution of 1 cm-1 and a path length of at least 2.0 m (6.6 ft), or equivalent gas analyzer

10.3.13 The composition of BESS unit vent gases shall be measured as outlined in Section 9.2.24. The hydrocarbon content may additionally be measured as outlined in accordance with 9.2.25 ~~using a Fourier-Transform Infrared Spectrometer with a minimum resolution of 1 cm-1 and a path length of at least 2.0 m (6.6 ft), total hydrocarbon analyzer, and hydrogen analyzer~~. The gas composition sampling port shall be located in the ceiling jet, 25-mm (1-in) below the ceiling

RATIONALE FOR DECISION:

In the 4th edition of UL 9540A, there is redundancy in the two measurement methodologies used to characterize the volume of flammable gas released during module and unit level testing (Flame Ionization Detection (FID) and Fourier Transform Infrared Spectroscopy (FTIR)). Both FTIR and FID were developed as required measurements for module and unit level testing in the first three editions of UL 9540A before data existed that enabled an understanding of the typical compositions of battery gas. Both FID and FTIR were specified as requirements because it was not clear that FID alone would provide an adequate characterization of all flammable gases released by batteries in thermal runaway. Therefore, FTIR was first intended to provide a means to quantify non-hydrocarbon flammable gases as well as to serve as a backup for FID measurement. FTIR, to a lesser degree, was also identified as a potential backup or improvement for CO and CO_2. Experience has demonstrated that an improvement to CO and CO_2 measurement is not necessary and a backup to non-dispersive infrared spectroscopy (NDIR) measurement has not been needed. Therefore, the FTIR will remain in the standard but as an optional additional measurement method.

In addition, hydrogen is measured with a hydrogen specific sensor, because neither FID or FTIR are capable of measuring hydrogen.

The list of equipment in Table 1 demonstrates overlap in the methodologies used for gas measurement.

Table 1 – Gas measurement equipment for fire and explosion hazards

Gas Hazard	Measurement Equipment
Hydrocarbons	1. Total unburned hydrocarbons by flame ionization detector (FID) 2. Individual components by Fourier Transform infrared spectrometry (FTIR)
Carbon monoxide (CO), Carbon dioxide (CO_2)	1. Individual components by non-dispersive infrared spectrometry (NDIR) 2. Individual components by FTIR
Hydrogen	1. Hydrogen sensor

INSTALLATION TEST REPORT
UL 9540A
Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems (AACD)

Project Number................................:	**4790648557**
Date of issue ....:	**2023-07-07**
Total number of pages...................:	**61**
UL Report Office ....:	**UL LLC**
Applicant's name...........................:	**SAMSUNG SDI CO LTD**
Address ....:	**428-5 GONGSE-DONG GIHEUNG-GU YONGIN-SI, GYEONGGI-DO 446-577 REPUBLIC OF KOREA**
Test specification:	4th Edition, Section 10, November 12, 2019
Standard ....:	UL 9540A, Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems
Test procedure ....:	10.1 – 10.8
Non-standard test method ....:	Requirements for the container test are not established in UL 9540A 4th edition, however, the requirements for the container system BESS in 10.6.2 in this report were in Certification Requirement Decision of UL9540A which is normative for the applicable UL Product Certification Program. No gas was measured by Fourier-Transform Infrared Spectrometer.

General disclaimer:

The test results presented in this report relate only to the sample tested in the test configuration noted on the list of the attachments.

UL did not select the sample(s), determine whether the sample(s) was representative of production samples, witness the production of the test sample(s), nor were we provided with information relative to the formulation or identification of component materials used in the test sample(s).

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Cell level information	
Cells in Module:	
● **Manufacturer Name**	Samsung SDI CO LTD
● **Part Number**	CP1495L101+
● **Chemistry**	LiNiCoAlO2
● **Format**	Prismatic
Ratings (Vdc, Ah) :	3.68 Vdc, 145 Ah
Cell certified? :	Yes
Standard the cell was certified to:	UL 1973
Organization that certified the cell:	UL Solutions (File Number: MH64496)
Average cell surface temperature at gas venting, °C:	166
Average cell surface temperature at thermal runaway, °C:	178
Gas Volume:	423
Lower flammability limit (LFL), % volume in air at the ambient temperature:	8.04
Lower flammability limits (LFL), % volume in air at the venting temperature:	6.74
Burning velocity (S_u) cm/s:	86.40
Maximum pressure (P_{max}) psig:	105.3

Cell level Gas Composition:

Gas	Measured %
Hydrogen	32.7 %
Carbon monoxide	40.9 %
Methane	15.43 %
Ethylene	0.56 %
Ethane	1.06 %
Carbon dioxide	9.2 %
Propene (Propylene)	0.04 %
Propane	0.03 %
C4 Total	0.05 %
C5 Total	0.01 %
Benzene	0.06 %
Total	**100 %**

Module level Information	
Module Manufacturer	
Model No.. :	E5S (MS3204L101A)
Ratings (Vdc, Ah)........................... :	110.4 Vdc, 290 Ah
Module dimensions (X x Y x Z (mm))……………….:	388.2 x 1751.8 x 155.0 (without mounting bracket)
Module cell configuration (xS/yP) …...:	30S/2P
Module weight (kgs)………………………. :	173
Module enclosure material……………….. :	Plastic Cover : PC(M3020PN), 2.5T Mica Sheet 0.3t(&Aerogel) Sheet
Was the module certified? ………………………….:	Yes
Standard the module was certified to …………..:	UL1973
Organization that certified test item …….:	UL Solutions (File Number: MH49407)
Number of initiating cells failed to achieve propagation.	1
Thermal Runaway Propagation:	Yes
External Flaming:	Yes
Location(s) of Flame Venting:	Flaming out of the top of the module
Flying Debris:	Yes
Re-ignitions:	No re-ignition
Test Maximum Smoke Release Rate (m^2/s)	7.06
Test Total Smoke Released: (m^2)	3516.04
Test Peak Chemical Heat Release Rate: (kW):	3935.15

Module level test Gas Composition & Volume for Each Compound (Pre-flaming and After flame) :

Gas Compound	Gas Type	Pre-Flaming (L)	Flaming (L)
Total Hydrocarbons (Propane Equivalent)	Hydrocarbons	6.61	677.14
Carbon Monoxide	Carbon Containing	Below detectable limit	39542.50
Carbon Dioxide	Carbon Containing	Below detectable limit	1421.12
Hydrogen	Hydrogen	*	*

*The hydrogen measurement system malfunctioned during the test, however, the same module design was tested with different charging specifications and the hydrogen quantity was below detectable limits. – Please refer to the report under UL project 4790648531

Unit level Information	
Unit Manufacturer	
Model No. :	PHR3843-001A (E5S)
Ratings (Vdc, Ah)............................ :	1324.8V, 290 Ah
BESS dimensions (W x **D** x **H** (mm)**)……………….:**	960.5 * 1752 * 2352 mm
BESS module configuration	12S/1P
Number of modules in BESS	24
Module cell configuration (xS/**y**P) **…...:**	30S/2P
Number of cells in module.:	60
BESS weight (kgs)……………………… :	2524 kg
BESS enclosure material……………….. :	Metal case, Plastic Cover, Mica(&Aerogel) sheet
BESS Intended Installation: **Non Residential:** outdoor ground mounted, indoor floor mounted, outdoor wall mounted, indoor wall mounted, roof top, open garage **Residential:** Outdoor ground mounted, indoor floor mounted, outdoor wall mounted, indoor wall mounted	Non-Residential indoor floor mounted.
Residential Indoor Use: Smallest volume room installations specified.	N/A
Original Equipment Manufacturer (OEM):	Samsung SDI Co LTD
Branding Manufacturer (if not OEM):	N/A
Was the unit certified? …………………………:	Yes
Standard the unit was certified to …………..:	UL 1973
Organization that certified the unit …….:	UL Solutions (File Number: MH49407)
Description of components employed within the unit that serve to suppress propagation (fire protection features) The BESS Unit includes the direct injection system consisting of smoke detection, fire control panel, pipes and a NOVEC cylinder as a fire suppression system. Once smoke is detected, a signal (signals from two smoke detectors) is sent to the fire control panel , which will open the solenoid valve on the NOVEC cylinder for NOVEC to be released into the integral suppression system pipes.	
Deviation from the module level test N/A	
Number of initiating cell(s)	1
Thermal Runaway Propagation:	No
External Flaming from BESS:	Yes
Location(s) of Flame Venting:	Front and Rear Top Surface
Maximum Target BESS Temperature, °C	31

Maximum Wall Surface Temperature[1], °C	169
Peak Chemical Heat Release Rate, kW	426.1
Peak Convective Heat Release Rate, kW	191.4
Maximum Smoke Heat Release Rate, m^2/s	1.1
Maximum Heat Flux on Target Modules, kW/m^2	0.70
Maximum Heat Flux of Egress Path, kW/m^2	6.60
Flying Debris:	No flying debris
Re-ignitions:	No reignitions

Gas Analysis:

☒ Flame ionization detection (FID)

☒ Non-Dispersive Infrared Spectrometer (NDIR)

☐ Fourier-Transform infrared Spectrometer

☒ Hydrogen Sensor (palladium-nickel, thin-film solid state sensor)

☒ White light source with photo detector (smoke release rate)

Summary of Unit level test Gas Analysis Data:

Unit level Gas Composition & Volume for Each Compound (Pre-flaming and After flame):

Gas Compound	Gas Type	Pre-Flaming (L)	Flaming (L)
Total Hydrocarbons (Propane Equivalent)	Hydrocarbons	Below detectable limit	3340.26
Carbon Monoxide	Carbon Containing	Below detectable limit	343.97
Carbon Dioxide	Carbon Containing	Below detectable limit	789
Hydrogen	Hydrogen	Below detectable limit	Below detectable limit

[1] Maximum wall surface temperature averaged on 60 seconds.

Installation level Information	
Integrator	
Model No. ……………….:	E5S container[2]
Installation type : (Room/Container) ……………….:	Container
Installation dimensions (W x **D** x **H** (mm)**)……………….:**	2455 x 3688 x 3049
Number of the units in the container in the test….:	5[3]
Unit configuration(xS/**y**P**) …...:**	5S1P
Standard the ESS system was certified	N/A The container assembly was not certified to UL 9540
Organization that certified the ESS system …….:	N/A
Power Conditioning System included (Yes/No**)…….:**	No
Power Conditioning system manufacturer	N/A
Power Conditioning system Model No.	N/A
Standard the power conditioning system was certified	N/A
Organization that certified the power conditioning system …….:	N/A
Test method used in the test (Method 1, Method 2, Container)	Container
Description of explosion prevention means within the ESS system [4] N/A	
Description of components employed within the ESS system that serve to suppress propagation (fire protection features) The racks were equipped with copper pipes with a set of fusible plastic plugs sleeved in and positioned above the cell vent area and the copper pipes were connected to a NOVEC 1230 cylinder (50kg) through a swaged nipple assembly to control the pressure. The Direct injection clean agent cooling system was designed to discharge the NOVEC 1230 until the cylinder was empty; there was no mechanism that could stop the direct injection clean agent cooling system in the middle of discharge. However, a series of dummy racks was installed as well in order to simulate the pressure drop generated from the pipes in the racks in the field other than the real racks involved in the test. The direct injection system was not certified as a component for an ESS or evaluated as part of an ESS certification.	
Deviation from the unit level test N/A	
Number of initiating cell(s)	1
Thermal Runaway Propagation:	No propagation observed during the test
External Flaming from BESS:	No external flaming observed
Flame length (m)	No external flaming observed

[2] Please note that there is no specific model number of the container used for the Installation level was provided.
3 Four units were populated with dummy modules that had no cells, and only one unit was populated with fully charged cells.
[4] Please note that the final design will not employ the deflagration panel(s) described above, however, these panels were used for the safety of testing. The panel was designed by Samsung SDI.

	Maximum Target BESS Temperature, °C	75
	Maximum Wall Surface Temperature[5], °C	670
	Maximum heat flux measured in the egress path(kW/m2)	0.001
	Flying Debris:	No flying debris
	Re-ignitions:	No re-ignition

Summary of Installation level Test Results

Performance Criteria

~~[]For BESS units intended for installation in locations with combustible construction, surface temperature measurements along instrumented wall surfaces **[did] [did not]** exceed a temperature rise of 97C (175° F) above ambient.~~ [6]

[X]The surface temperature of modules within the BESS units adjacent to the initiating BESS unit ~~**[did]**~~ **[did not]** exceed the temperature at which thermally initiated cell venting occurs, as determined in 7.3.1.8.

[X]The fire spread on the cables in the flame indicator ~~**[did]**~~ **[did not]** extend horizontally beyond the initiating BESS enclosure dimensions.

[X]There ~~**[was]**~~ **[was no]** flaming outside the test room.

[X]There ~~**[was]**~~ **[was no]** observation of detonation.

[X]There ~~**[was]**~~ **[was no]** observation of deflagration, ~~[ ] which **[was] [was not]** mitigated by an engineered deflagration protection system~~.

[X]Heat flux in the center of the accessible means of egress ~~**[did]**~~ **[did not]** exceed 1.3 kW/m^2.

[X]There ~~**[was]**~~ **[was no]** observation of re-ignition within the initiating unit after the installation test had been concluded and the fire suppression system was discontinued

Necessity of a re-test

[X] An installation level test did meet the applicable performance criteria noted above, therefore the ESS system under test would not need to be revised and retested

[ ] An installation level test did not meet the applicable performance criteria noted above, therefore the ESS system under test would need to be revised and retested

Testing Laboratory Information

Testing Laboratory and testing location(s):

Testing Laboratory:	Samsung SDI CO LTD	
Testing location/ address ....:	163, Bangudae-ro, Samnam-eup Ulsan, Ulju-gun,44953, Republic of Korea	
Tested by (name, signature) ....:	KwangDeuk Lee	
Witnessed by (for 3rd Party Lab Test Location)	Leon Lee	Leon Lee

5 Maximum wall surface temperature averaged on 60 seconds.

6 Surface temperature rise is not applicable if the intended installation is composed completely of noncombustible materials in which wall assemblies, cables, wiring and any other combustible materials are not intended to be present in the BESS installation. In this case, the report shall note that the installation shall contain no combustible materials.

(name, signature) ....:		
Project Handler (name, signature)...............:	Leon Lee	Leon Lee
Reviewer (name, signature) …………….:	Sean Yang	

List of Attachments (including a total number of pages in each attachment):
Attachment A: Sample Charging, OCV and SOC Measurement Profiles - (*Pages **31** through **32***)
Attachment B: BESS (including module and any integral fire detection and suppression systems) Construction Photos/Diagrams - (*Pages **33** through **34***)
Attachment C: BESS and Equipment Instrumentation and Test Installation Layout Photos/Diagrams - (*Pages **35** through **40***)
Attachment D: Temperature Profiles and Heat Flux Measurements During Testing (Initiating Cell and Module, Target Modules, Wall Surfaces, etc. - (*Pages **41** through **44***)
Attachment E: BESS Unit Testing and Post Testing Photos - (*Pages **45** through **49***)
Attachment F: Fire suppression system and deflagration mitigation system – (*Pages **50** through **55***)
Attachment G: Certification Requirement Documents **(***Pages **56** through **61***)

Photo(s) of ESS System:

Figure 1 – Picture of the units in the container

Figure 2 – Picture of the container

Test Item Charge/Discharge Specifications:	**Per module**
• **Charge current, A:**	90.0
• **Standard Full charge voltage, Vdc:**	124.5
• **Charge temperature range, °C:**	23 ± 5 °C
• **End of charge current, A:**	58.0
• **Discharge current, A:**	58.0
• **End of discharge voltage, Vdc:**	93.0

• **Discharge temperature range, °C:**	23 ± 5 °C

Photo(s) of Fire protection system:

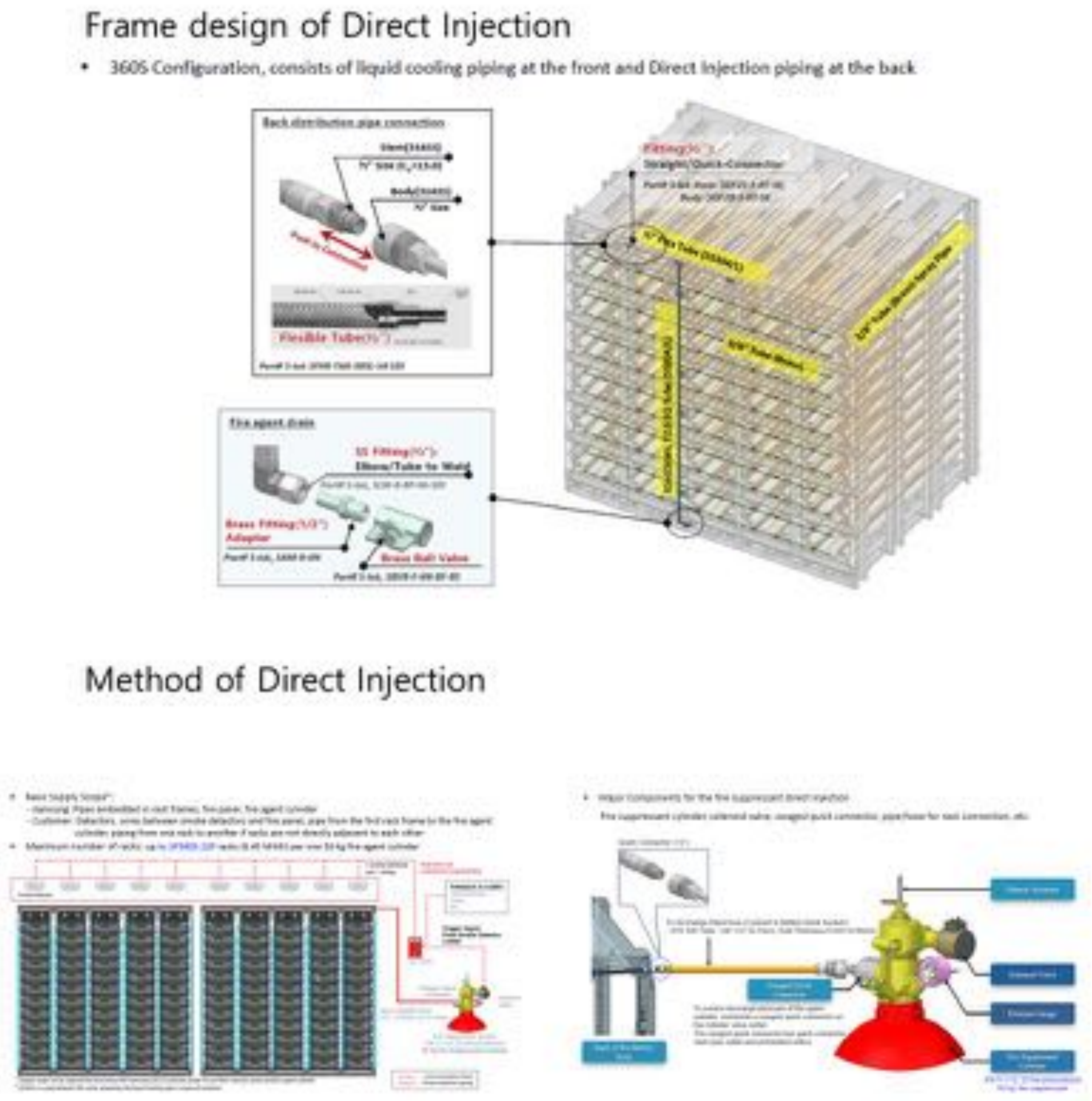


Figure 3 – Principle of the direct injection system, as per Samsung SDI

Specifications:	
• **Manufacturer:**	Samsung SDI CO. LTD
• **Model No.:**	Direct injection system
• **Suppressant Name:**	NOVEC 1230
• **Pipes diameter**	5/16"(Brass)
• **Suppressant storage type**	NOVEC 1230 cylinder
• **Initial pressure of the suppressant storage:**	362psig
• **Nozzle type**	Fusible plug
• **Number of the nozzles**	60 per module (one per cell)
• **Control panel Model No.**	V802-00121A(Fire Alarm Control Panel) V802-00122A(Module Box)
• **Smoke Detector type**	Photoelectric
• **Smoke Detector Model No.**	CPS-24

Photo(s) of (Deflagration mitigation) means:[7]

Specifications:	
• **manufacturer**	FDC CO., LTD
• **Model No.**	Explosion panel (2D0949-001)
• **Rating**	0.2 bar at Ambient temperature
• **Dimensions (W X D X H)**	1 m X 1 m
• **Location in the system/container**	On the ceiling

7 Please note that the final design will not employ the deflagration panel(s) described above, however, these panels were used for the safety of testing. The panel was designed by Samsung SDI.

Test item particulars ....:	
Possible test case verdicts:	
- test case does not apply to the test object...........:	N/A
- test object does meet the requirement ....:	P (Pass)
- test object does not meet the requirement...........:	F (Fail)
- test object was completed per the requirement...:	C(Complete)
- test object was completed with modification……:	M(Modification)
Testing..:	
Date of receipt of test item ....:	2023-03-20
Date (s) of performance of tests ....:	2023-03-22

General remarks:

"(See Enclosure #)" refers to additional information appended to the report.
"(See appended table)" refers to a table appended to the report.

Throughout this report a point is used as the decimal separator.

Manufacturer's Declaration of samples submitted for test:

The applicant for this report includes samples from more than one factory location and a declaration from the Manufacturer stating that the sample(s) submitted for evaluation is (are) representative of the products from each factory has been provided ....:	☐ **Yes** ☒ **Not applicable**
Name and address of factory (ies) .... :	163, Bangudae-ro, Samnam-myeon, Ulju-gun, Ulsan, Republic of Korea

General product information and other remarks:

Direct injection system container is a customized container (2455mm x 3688mm x 3049mm) equipped with two 1m by 1m deflagration panels on the top. The container did not have any suppression system other than the integral cooling system Samsung SDI designed. The racks used in the test was PHR3843-001A, which consists of modules (MS3204L101A) that has 60 of CP1495L101+ cells manufactured by Samsung SDI.

	CONSTRUCTION		Verdict
5.3	**Battery energy storage system unit Construction**		—
5.3.1, 5.3.2	Construction information	See Test Item Description at the beginning of this report	—
5.3.2	General layout of BESS unit contents	See Attachment B	—
5.3.3	Details of integral fire suppression system	See Attachment C	
5.3.1	BESS certified to UL 9540	Not certified to UL9540	C
	Organization that certified BESS:		—
	PERFORMANCE		**Verdict**
6	**General**		
10	**Installation Level**		
10.1	**General**		
10.1.1	The installation level test method assesses the effectiveness of the fire and explosion mitigation methods for the BESS in its intended installation. a) Test Method 1 – "Effectiveness of sprinklers" is used to evaluate the effectiveness of sprinkler fire protection and explosion mitigation methods installed in accordance with code requirements. b) Test Method 2 – "Effectiveness of fire protection plan" is used to evaluate the effectiveness of other fire and explosion mitigation methods (e. g., gaseous agents, water mist systems, combination systems). c) Test Method 3 – Container System BESS installation level test	Requirements for the container test are not established in UL 9540A 4th edition, however, the requirements for the container system BESS in 10.6.2 in this report were in Certification Requirement Decision of UL9540A which is normative for the applicable UL Product Certification Program.	C
10.1.2	Installation level testing is not appropriate for units only intended for outdoor use or residential use.	Container (Installation) level test	N/A
	Container system BESSs as defined in this standard, although typically for outdoor use installations, are included in the installation level test as the container represents a type of installation that may be provided with integral fire detection and suppression and integral explosion or deflagration protection.	The integral fire suppression system (the direct injection system) was installed in the test. Please note that the final design will not employ the deflagration panel(s) described above, however, these panels were used for the safety of testing. The panel was designed by Samsung SDI.	C
10.2	**Sample and test configuration**		

UL 9540A, Edition 4,			
Clause	Requirement + Test	Result - Remark	Verdict
10.2.1	The samples (initiating BESS and target BESS) and their preparation for testing, including separation distances from walls, shall be identical to that used for the unit level test in Section 9	See Table 2 and Attachment C for test installations	C
10.2.2	A flame indicator consisting of a cable tray with fire rated cables that complies with UL 1685 and representative of the installation per the manufacturer's specifications was deployed above the BESS at a distance specified by end-use installation.	See Attachment C for test installations	N/A
	If the installation requires that cabling be installed below the BESS, then the flame indicator is not needed.		N/A
10.2.3	For container system BESS, the units utilized for initiating and target units are the battery system racks that are installed within the container. The container system BESS was populated with one initiating unit chosen as the location within the container that may result in worse case results and target units installed around and across the initiating BESS representative of the intended container layout.		C
	The Integral fire detection and suppression systems were installed in the system for the test.	The integral fire suppression system (the direct injection system) was installed in the test. Please note that the final design will not employ the deflagration panel(s) described above, however, these panels were used for the safety of testing. The panel was designed by Samsung SDI.	C
	Any wiring within the container either intended to be installed above the units or along them horizontally, that can be a source of fire spread, should be included in the container for the test.	No wiring either intended to be installed above the units or along them horizontally, that can be a source of fire spread in the container.	N/A
	Equipment mounted to openings in the container that may impact air flow and therefore test results, was included in the installation for the test.	No equipment mounted that may impact air flow in the container.	N/A
	Internal equipment such as a power conditioning/conversion system or switchgear, can be represented by their enclosures or other simulation means for temperature measurement purposes	No power conditioning/conversion system was included in the container.	N/A
10.3	**Test method 1 – Effectiveness of sprinklers**		

UL 9540A, Edition 4,			
Clause	Requirement + Test	Result - Remark	Verdict

10.3.1	For BESS units with a height of 2.44 m (8 ft) or less,, The test was conducted in a 6.10 × 6.10 × 3.05-m (20 × 20 × 10-ft) high test room with one open 1.22 × 2.13-m (4 × 7-ft) high doorway or a room representative of the installation configuration as specified by the manufacturer.	See Attachment C for test installations	N/A
	The smallest test room anticipated by the manufacturer for BESS deployments, including footprint and ceiling height, was tested.		N/A
	For BESS units taller than 2.44 m (8 ft), the ceiling height was increased to be at least 0.61-m (2-ft) higher than the BESS units under test.	See Attachment C for test installations	N/A
	The explosion mitigation methods was installed in the test installation in accordance with the manufacturer's specifications.	See Attachment C for test installations	N/A
	Pressure sensors was installed at deflagration vents to determine the maximum pressure developed during the test.	Pressure sensors were installed at the top and sides of the container to measure the maximum pressure developed during the test. Please refer to Figure F8.	C
10.3.2	The test room was fitted with four sprinklers at 3.05-m (10-ft) spacing in the center of the test room.		N/A
	The sprinkler was standard spray, standard response with a temperature rating of 93° C (200° F), a nominal K-factor of 5.6, and sprinkler water density of 12.22 L/m2/min (0.3 gpm/ft2).		N/A
	If different specifications for the sprinklers with other densities, ratings and K-factors are indicated in the installation specifications, those were used for the installation test instead.		N/A
10.3.3	Walls were constructed with 16-mm (5/8-in) gypsum wall board. Instrumented wall sections were painted flat black.		N/A
10.3.4	The initiating BESS unit was positioned at manufacturer specified distances from test room instrumented walls and target BESS units	See Attachment C for test installations	N/A
10.3.5	Temperature measurements at the ceiling locations directly above the initiating and target BESS unit were collected by an array of thermocouples located 25-mm (1-in) below the ceiling and at 152-mm (6-in) intervals using No. 24-gauge Type-K exposed junction thermocouples		C

UL 9540A, Edition 4,			
Clause	Requirement + Test	Result - Remark	Verdict
10.3.6	Instrumented wall surface temperature measurements were collected in a vertical array at 152- mm (6-in) intervals for the full height of the instrumented wall sections using No. 24-gauge Type-K exposed junction thermocouples to measure wall surface temperatures. Thermocouples were positioned in the wall locations anticipated to receive the greatest thermal exposure from the initiating BESS unit.		C
10.3.7	Thermocouples for wall surface temperature measurements were secured to gypsum surfaces by the use of staples placed over the insulated portion of the wires. The thermocouple tip was depressed into the gypsum so as to be flush with the gypsum surface at the point of measurement and held in thermal contact with the surface at that point by the use of pressure-sensitive paper tape.		N/A
10.3.8	Heat flux was measured with at least two water-cooled Schmidt-Boelter gauges at the surface of each instrumented wall: a) Both are collinear with the vertical thermocouple array; b) One is positioned to receive the greatest heat from the initiating module; and c) One is positioned to receive the greatest heat flux during potential propagation within the initiating BESS unit.	No wall was used for the test.	N/A
10.3.9	Heat flux was measured with 2 water-cooled Schmidt-Boelter gauges at the surface of each adjacent target BESS units facing initiating BESS unit: a) One is positioned at the elevation estimated to receive the greatest heat flux from the initiating module; and b) One is positioned at the elevation estimated to receive the greatest surface heat flux due to initiating BESS.	Only one heat flux gauge was installed in each target unit at the elevation estimated to receive the greatest heat flux due to the thermal runaway of the initiating module. No secondary heat flux was installed because: • the distance between each target unit and the initiating unit is 0 mm; and based upon engineering discretion, flaming was expected near the initiating module, and it was assumed that the area that would experience the greatest surface heat flux during thermal runaway in the initiating BESS was right next to the initiating module.	C

UL 9540A, Edition 4,			
Clause	Requirement + Test	Result - Remark	Verdict

10.3.10	Heat flux was measured with the sensing element of at least one water-cooled Schmidt-Boelter gauge positioned in the center of the accessible means of egress.	Heat flux gauge was installed outside the container vertically and horizontally in line with the initiating cell. The distance between the gauge and the container was 0mm	C
10.3.11	No. 24-gauge or smaller Type-K exposed junction thermocouples were installed to measure the surface temperature of module enclosures within target BESS units. Three thermocouples were located at positions on the exterior of each module enclosure, nearest to the initiating BESS unit.		C
	A minimum of two, No. 24-gauge or smaller Type-K thermocouples were placed within each module to provide data to monitor the thermal conditions within non-initiating modules.		C
	Additional thermocouples may be placed to account for convoluted enclosure interior geometries.		N/A
10.3.12	An internal fire condition in accordance with the module level test was created within a single module in the initiating BESS unit: a) The position of the module was selected to present the greatest thermal exposure to adjacent modules (e. g. above, below, laterally), based on the results from the module level test; and b) The setup (i.e. type, quantity and positioning) of equipment for initiating thermal runaway in the module was the same as that used to initiate and propagate thermal runaway within the module level test (Section 8).		C
10.3.13	The composition of BESS unit vent gases was measured using a Fourier-Transform Infrared Spectrometer with a minimum resolution of 1 cm-1 and a path length of at least 2.0 m (6.6 ft), total hydrocarbon analyzer, and hydrogen analyzer. The gas composition sampling port was located in the ceiling jet, 25-mm (1-in) below the ceiling.	FTIR was not used in the test as the gas measurements were performed from the cell level to the unit level test. Please refer to Attachment G.	M
10.3.14	The test was terminated because: a) Temperatures measured inside each module of the initiating BESS return to below the cell vent temperature; b) The fire propagates to adjacent units or to adjacent walls; or c) A condition hazardous to test staff or the test facility requires mitigation.		C

UL 9540A, Edition 4,			
Clause	Requirement + Test	Result - Remark	Verdict
10.3.15	The initiating unit was under observation for 24 h after conclusion of the installation test to determine that re-ignition did not occur		C
10.3.16	**Container System BESS**		
10.3.16.1	A container system BESS that utilized sprinkler system fire suppression was tested in accordance with 10.3 except instead of the test room, the actual container was used as the test room		C
10.3.16.2	The installation included any targets representing major components (e.g. power conditioning system) installed within the container system, and temperatures were measured on these targets similar to the approach used for measuring temperatures on walls.		C
	The target can be represented by the equipment enclosure or a wall or other means placed in a similar manner to represent the location and layout of the components.		C
10.6	**Test method 2 – Effectiveness of fire protection plan**		
10.6.1	The test method 2 test set-up and test procedures are identical to that in 10.3, except instead of the sprinkler system set up of 10.3.2, the room shall be fitted with the specified fire protection and explosion mitigation equipment representative of a planned installation for the tested BESS system		N/A
10.6.2	**Container System BESS – Test Method 2**		
10.6.2.1	A container system BESS that utilizes an alternative fire suppression system shall be tested in accordance with 10.6 except instead of the test room, the actual container shall be used as the test room.	See Attachment C for test installations	C
10.6.2.2	The installation shall include any targets representing any major components (e.g. power conditioning system) installed within the container system and temperatures shall be measured on these targets similar to the approach used for measuring temperatures on walls.	Temperatures were measured on the cover of chiller (No chiller was filled in but just enclosure was used). See Attachment C for test installations	C
	The target can be represented by the equipment enclosure or a wall or other means placed in a similar manner to represent the location and layout of the components.		C
10.4	**Installation level test report**		
10.4.1	The report on installation level testing shall include the following:		

UL 9540A, Edition 4,			
Clause	Requirement + Test	Result - Remark	Verdict

	a. Unit manufacturer name and model number (and whether compliant with UL 9540 or UL 1973); and the container system BESS manufacturer name and model number (and whether compliant with UL 9540) if container system;	The unit was certified to UL1973, however, the system including the direction injection system and the container, was not certified to the respective applicable standard.	C
	b. Number of modules in the initiating BESS unit	12 Modules	C
	c. The construction of the initiating BESS unit per 5.3 and the number of battery system racks and overall construction within the container for a container system BESS;	See Attachment C See Critical Components Table ☐ See Also "Description of components employed within the module that impact propagation (fire protection features)" at the beginning of this report.	C
	d. Module voltage(s) of initiating BESS corresponding to the tested SOC	Initiating voltage was measured during charging and the test.	C
	e. The thermal runaway initiation method used	External heating method, used for cell, module, and unit level test, was used for the container level test.	C
	f. Diagram and dimensions of the test setup including location of the initiating and target BESS units, and the locations of walls and ceilings, and location of included internal target components in the container system BESS (e.g. target integral power conditioning system or integral switch gear enclosure, etc.)	See Attachment C	C
	g. Location of initiating module within the BESS unit;	See Attachment C	C
	h. Separation distances from the initiating BESS unit	See Attachment C	C
	i. Separation distances from the initiating BESS unit to target BESS units	See Attachment C	C
	j. Distances of the flame indicator (if used) with respect to the BESS	See Attachment C	N/A
	k. Maximum temperature at the ceiling;	See Table 7	C
	l. Distance of fire spread within the flame indicator or indication of fire spread through wiring in a container system BESS;	No fire indicator was installed as specified by applicant. However, the thermocouple array was installed to measure the ceiling temperatures.	N/A
	m. The maximum wall surface and target BESS unit temperatures achieved during the test and the location of the measuring thermocouple;	Tables 5 and 6	C

UL 9540A, Edition 4,			
Clause	Requirement + Test	Result - Remark	Verdict

	n. The maximum incident heat flux on target wall surfaces and target BESS units;	Target wall heat flux was not measured because the heat flux can be occluded by the target units on both sides of the initiating unit	M
	o) Voltages of initiating BESS		C
	p) Total number of sprinklers that operated and length of time the sprinklers operated during the test;	No sprinklers was installed during the test, however, the number of the Novec 1230 nozzles in the unit per module (60 per module) was provided in the report	N/A
	q. Gas generation and composition data, if measured		N/A
	r. Observation of flaming outside of the test room;	No flaming observed during the test	C
	s. Observation of installed explosion protection operation;	No explosion observed during the test	C
	t. Observation of flying debris or explosive discharge of gases;	No flying debris observed during the test	C
	u. Observation of re-ignition(s) from thermal runaway events;	No re-ignition observed during and after the test	C
	v. Observations of the damage to: 1) The initiating BESS unit; 2) Target BESS units; and 3) Adjacent walls;	See Figure E1 through Figure E5	C
	w. Photos and video of the test	Videos were recorded by Samsung SDI; this report provides the snapshots of the videos to indicate the major events.	C
	x. Fire protection features/detection/suppression systems within unit; and	Pressure and flow rate of NOVEC 1230 was measured during the test.	C
	y. Explosion and deflagration protection		C
	z. Sprinkler K-factor, RTI, manufacturer and model, number of sprinklers and layout, and length of time of operation of the sprinklers.	No sprinklers were installed for the test.	N/A
	Installation level test report – Test method 2 – Effectiveness of fire protection plan		

UL 9540A, Edition 4,			
Clause	Requirement + Test	Result - Remark	Verdict
	The report on installation level testing shall include the following: a) The report information in 10.4.1 items (a) – (u), and (v) if applicable;		C
	b) Fire protection features/detection/suppression systems within installation; and		C
	c) Length of time of operation of the clean agent, or other suppression system in addition to any sprinklers used.		N/A
10.8	**Performance – Test method 2 – Effectiveness of fire protection plan**		
	See 10.5 for performance criteria.		C
10.5	**Performance at Installation level testing**		
10.5.1[8]	For BESS units intended for installation in locations with combustible construction, surface temperature measurements along instrumented wall surfaces shall not exceed a temperature rise of 97°C (175°F) above ambient.	The container door material was metal, therefore, it is non-combustible.	N/A
10.5.2	The surface temperature of modules within the BESS units adjacent to the initiating BESS unit shall not exceed the temperature at which thermally initiated cell venting occurs, as determined in 7.3.1.8.	The maximum temperature measured on the target units was 74°C and the vent temperature obtained from the cell level test was 166°C	P
10.5.3	The fire spread on the cables in the flame indicator shall not extend horizontally beyond the initiating BESS enclosure dimensions	No flame indicator was needed.	N/A
10.5.4	There shall be no flaming outside the test room.	No flaming observed outside the container	P
10.5.5	There is no observation of detonation. There is no observation of deflagration unless mitigated by an engineered deflagration protection system	No observation of explosion during the test	P
10.5.6	Heat flux in the center of the accessible means of egress shall not exceed 1.3 kW/m2.	Heat flux measured right in contact with the back side of the container was measured 0.001 W/m2	P

[8] Surface temperature rise is not applicable if the intended installation is composed completely of noncombustible materials in which wall assemblies, cables, wiring and any other combustible materials are not to be present in the BESS installation.

UL 9540A, Edition 4,			
Clause	Requirement + Test	Result - Remark	Verdict

10.5.7	There shall be no observation of re-ignition within the initiating unit after the installation test had been concluded and the sprinkler operation was discontinued	No observation of re-ignition after the test was completed.	P
10.5.9.1	For container system, temperatures on any combustible construction within the container including target components shall not exceed a temperature rise of 97°C (175°F) above ambient	There is not any combustible construction within the container except for Unit. The maximum temperature measured on the target units was 74°C.	P
	There shall be no flaming outside of the container	No flaming observed outside the container	P

Table 1 – Specified Unit charging and discharging parameters			
Charging:		**Discharging:**	
Current (CC), A	90.0	Current (CC), A	58.0
Standard Full Charge Voltage ,Vdc	124.5	End of discharge voltage ,Vdc	93.0
End of charge current, A	58.0	Discharging Test Ambient, °C	23 ± 5
Refer to Attachment A for charge/discharge profiles.			

Table 2 - Test Initiation Details	
Test Date	2023-03-22
Test Start Time (HH:MM:SS)	02:09:34
Initial Lab Temperature, °C	22.0
Initial Relative Humidity % RH	53
Module OCV at Start of Test, Vdc	123.2

Table 1 – Approximate time of thermal runaway propagation through module			
Locations (Cell #)	**Event**	**Time**	**Temperature of the cell**
Initiating cell (Cell 33)	Venting	00:39:06	152
Initiating cell (Cell 33)	Thermal Runaway	00:40:13	165

Table 4 – Test overview timeline		
Time (HH:MM:SS)	**Event**	**Description**
00:00:00	Test Start	Test started and the initiating cell(cell 33) was heated by monitoring the temperature from the thermocouple instrumented on the cell side not covered by the heater.
00:39:06	Vent	Off gas generated from the initiating module and the temperature on the cell experienced a sudden drop. The temperature was controlled back to the range of 4 to 7 °C/min.
00:40:13	Thermal runaway	Gas was released from the module from 00:39:06, however, the data collected showed the temperature rise on the initiating cell in an uncontrollable manner from 00:40:13.
00:40:15	Ignition flaming	Ignition flaming was observed. (2 seconds after Thermal runaway)

00:40:24	First Smoke Detection	Following the release of venting gas, the first smoke detectors located at the top of the BESS unit activate and sends a sign to the NOVEC System.
00:40:26	Second Smoke Detection	The second smoke detection was turned on
00:40:26 - 00:52:38	Suppressant released	The flow rate measured through the flow meter confirmed that suppressant started flowing into the system at 00:40:26 and it ended at 00:52:38 After 00:52:38, nitrogen that pressurized the NOVEC in the cylinder was released, which was confirmed by the pressure increase.
02:19:57	Test Terminated	Data Acquisition was stopped however, the container was left in the testing room overnight.

Table 5 - Maximum Temperatures in Target Units					
Cell vent temperature from cell test data, °C			166		
Target Unit 1					
Module Location No.	Temper-ature (°C)	Module Location No.	Temper-ature (°C)	Module Location No.	Temper-ature (°C)
Target1Mod10Front	23	Target1Mod4Front	31	Target1Mod8Rear	24
Target1Mod10Center	37	Target1Mod4Rear	24	Target1Mod9Front	37
Target1Mod10Rear	25	Target1Mod5Front	29	Target1Mod9Rear	26
Target1Mod1Front	29	Target1Mod5Rear	24	Target1Mod11Front	51
Target1Mod1Rear	25	Target1Mod6Front	29	Target1Mod11Rear	24
Target1Mod2Front	30	Target1Mod6Rear	24	Target1Mod12Front	74
Target1Mod2Rear	24	Target1Mod7Front	31	Target1Mod12Rear	27
Target1Mod3Front	28	Target1Mod7Rear	24		
Target1Mod3Rear	24	Target1Mod8Front	38		
Target Unit 2					
Module Location No.	Temper-ature (°C)	Module Location No.	Temper-ature (°C)	Module Location No.	Temper-ature (°C)
Target2Mod10Front	23	Target2Mod4Front	32	Target2Mod8Rear	23
Target2Mod10Center	34	Target2Mod4Rear	24	Target2Mod9Front	26
Target2Mod10Rear	24	Target2Mod5Front	34	Target2Mod9Rear	24
Target2Mod1Front	39	Target2Mod5Rear	23	Target2Mod11Front	26
Target2Mod1Rear	40	Target2Mod6Front	26	Target2Mod11Rear	24
Target2Mod2Front	33	Target2Mod6Rear	23	Target2Mod12Front	43
Target2Mod2Rear	33	Target2Mod7Front	25	Target2Mod12Rear	24
Target2Mod3Front	32	Target2Mod7Rear	23		
Target2Mod3Rear	25	Target2Mod8Front	24		

Table 6 - Maximum Temperatures on the door[9] in front of the initiating unit					
Ambient Temperature:22°C					
UL 9540A performance criteria, Ambient + 97°C:119°C.[10]					
Height, mm	Maximum Temperature (°C)	Height, mm	Maximum Temperature (°C)	Height	Maximum Temperature (°C)
6in.	424	42in.	562	78in.	312
12in.	472	48in.	488	84in.	220
18in.	557	54in.	327	90in.	240
24in.	559	60in.	416	96in.	152
30in.	670	66in.	351	102in.	171
36in.	665	72in.	352		
Note: Temperatures are measured constantly and then averaged every 60-seconds					

Table 7 - Maximum Temperatures on the ceiling of the container					
Ambient Temperature:22°C					
UL 9540A performance criteria, Ambient + 97°C:119°C[11]					
Height, mm	Maximum Temperature (°C)	Height, mm	Maximum Temperature (°C)	Height	Maximum Temperature (°C)
6in.	266	54in.	423	102in.	139
12in.	154	60in.	107	108in.	209
18in.	145	66in.	237	114in.	197
24in.	187	72in.	214	120in.	218
30in.	271	78in.	241	126in.	280
36in.	198	84in.	270	132in.	319
42in.	245	90in.	483	138in.	387
48in.	326	96in.	246	102in.	139
Note: Temperatures are measured constantly and then averaged every 60-seconds					

Table 8 – Heat Flux Measurements	
Summary of maximum heat flux in target units	
Maximum Heat Flux, kW/m^2	
Target 1 Module No.10:	0.015
Target 2 Module No.10:	0.015
Egress path measurement:	0.001

[9] Per the container layout, temperatures were measured on the chiller box.
[10] The criteria is not applicable, the door is not combustible.
[11] The criteria is not applicable, the ceiling is not combustible.

Table 9 – Integral Fire suppression system Details of Operation		
Time of operation of Sprinklers/Suppression System:	Time of Operation Start (HH:MM:SS)	Time after thermal runaway (HH:MM:SS)
First Smoke detection	00:40:24	00:00:11
Second Smoke detection	00:40:26	00:00:13
NOVEC released	00:40:26	00:00:13

Table 10 – Other Observations during Installation level test			
	Observed, Yes/No	Comments/Location	
Flaming outside of Unit	No	Length of flame:	No flaming observed
Flying debris	No	-	
Explosive discharge of gas	No	-	
Sparks or electrical arcs	No	-	

Table 11 - Post Test Observations	
Thermal runaway behaviour	No
Re-ignitions	No
Explosions	No
Other Observations	No

	TABLE: Critical components information				
Object / Part No.	**Manufacturer/ trademark**	**Type / model**	**Technical data**	**Standard**	**Mark(s) of conformity[1)]**
Cell	SAMSUNG SDI CO LTD	CP1495L101+	3.68 Vdc, 145 Ah	UL1973	UL Recognized
Module	SAMSUNG SDI CO LTD	MS3204L101A	2P30S/, 110.4Vdc, 290 Ah	UL1973	UL Recognized
Unit Enclosure	SAMSUNG SDI CO LTD	PHR3843-001A	2P360S 1324.8Vdc, 280Ah	UL1973	UL Recognized
Rack Assembly for module	Samsung SDI	SGHC/SGCC	Thickness: 3.2 mm Dimension: 960.5 mm x 1752 mm x 2352 mm	-	-
Rack Assembly for BCU	Interchangeable	SGHC/SGCC	Thickness: 3.2 mm Dimension: 960.5 mm x 1752 mm x 2352 mm	-	-
Liquid cooling system (*normal operations*)	SAMSUNG SDI CO LTD	Liquid Cooling system	-	-	-
Wiring	JHOSIN HONGLIN TECHTRON	Type3817	AWG1, 125℃	UL758	UL Approved
Thermal Insulating Materials	HANJUNG NCS CO., LTD	Mica, Aerogel			
Smoke Detectors	POTTER	PAD300-PD	Addressable Smoke Detector	UL268	Listed (S24776)
Fire Control Panel	POTTER	IPA-100	Addressable FACP	UL864	Listed (S735)
Suppressant	3M	FK-5-1-12, 3MTMNovecTM1230 Fire Protection Fluid	>50kg of Novec Fluid, 360psi with nitrogen	-	-
NOVEC cylinder	GFI	F1230-CYL-58	-	-	-
Swaged Nipple Assy	GFI	SQF2S-1-7/ 8-12UN-OF1.5- SDI-S6	Orifice 1.50	-	-

UL 9540A, Edition 4,			
Clause	Requirement + Test	Result - Remark	Verdict

Solenoid Valve	Fiwarec	F1120045	- 20 to 50 ℃	UL 864	UL Approved (S35768)
Plastic plug	LOTTE Chem	PP J-320	-	-	-
Pipes	Hanjung NCS	Brass	3/8”	-	-

List of test equipment used:

A completed list of used test equipment shall be provided in the Test Reports when a Customer's/Third Party Testing Facility has been used.

Testing / measuring equipment / material used, (Equipment ID)	Range used	Last Calibration date	Calibration due date
Battery cycler	EVT 150-1200-1 Thy/ 1200V, 150A	2022-05-12	2023-05-12
Data Acquisition System (DL850E)	500°C/200V	2022-06-24/ 2022-06-15	2023-06-24/ 2023-06-15
Data Acquisition System (Fluke)	500°C/150V	2022-04-25/ 2022-04-11	2023-04-25/ 2023-04-11
Digital Multimeter	FLUKE 1000V	2022-05-31	2023-05-31
Electronic scales	CKE162 200kg	2022-05-13	2023-05-13
Stop watch	CASIO 86400 s (24hr)	2021-08-26	2023-08-26
Measuring tape	TAJIMA 7m	2022-11-08	2023-1108
Temperature and humidity recorder	608-H1 30.0% to 70.0%, 10.0°C to 30.0°C	2022-10-31	2023-10-31

Attachment A: Sample Charging, OCV and SOC Measurement Profiles - (*Pages **31** through **32***)

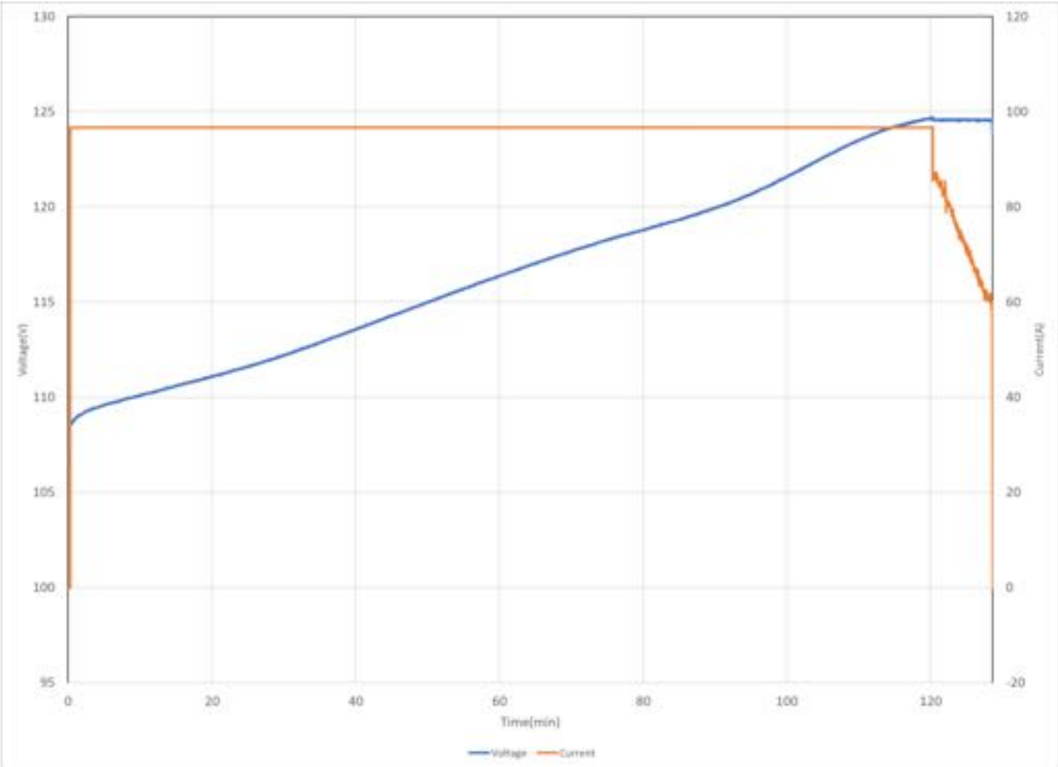


Figure A1 – Initiating module (module 10) charge profile

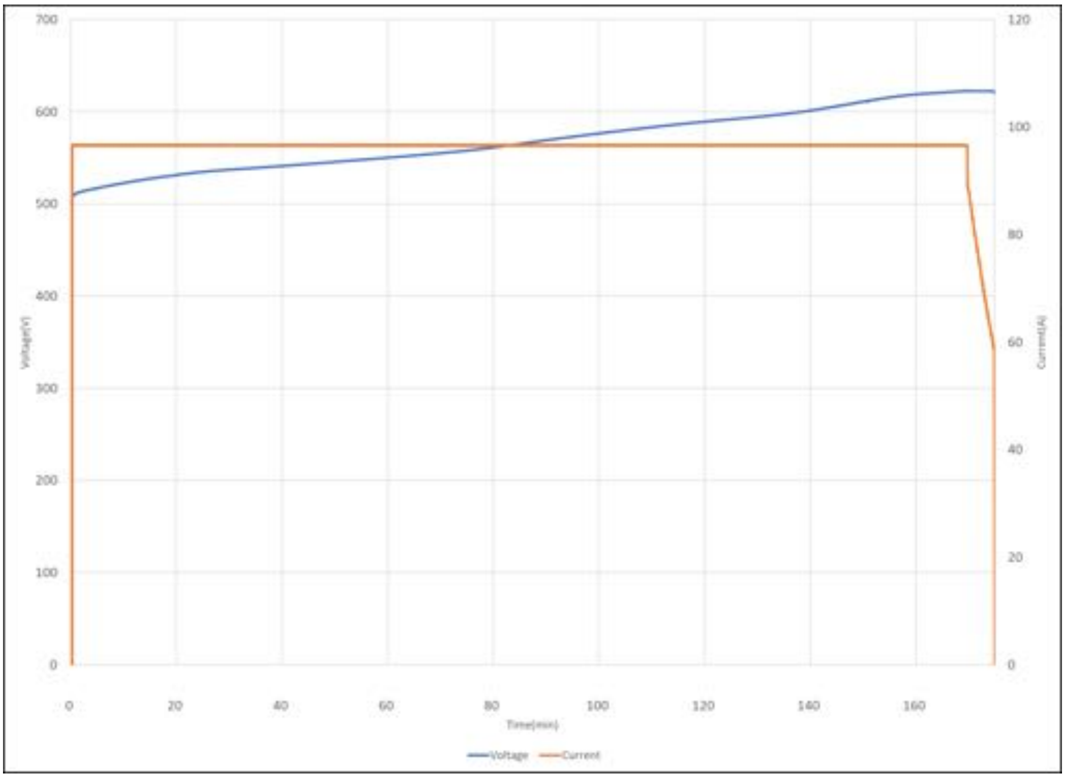


Figure A2 – Module 1 to 5 charge profile, connected in series

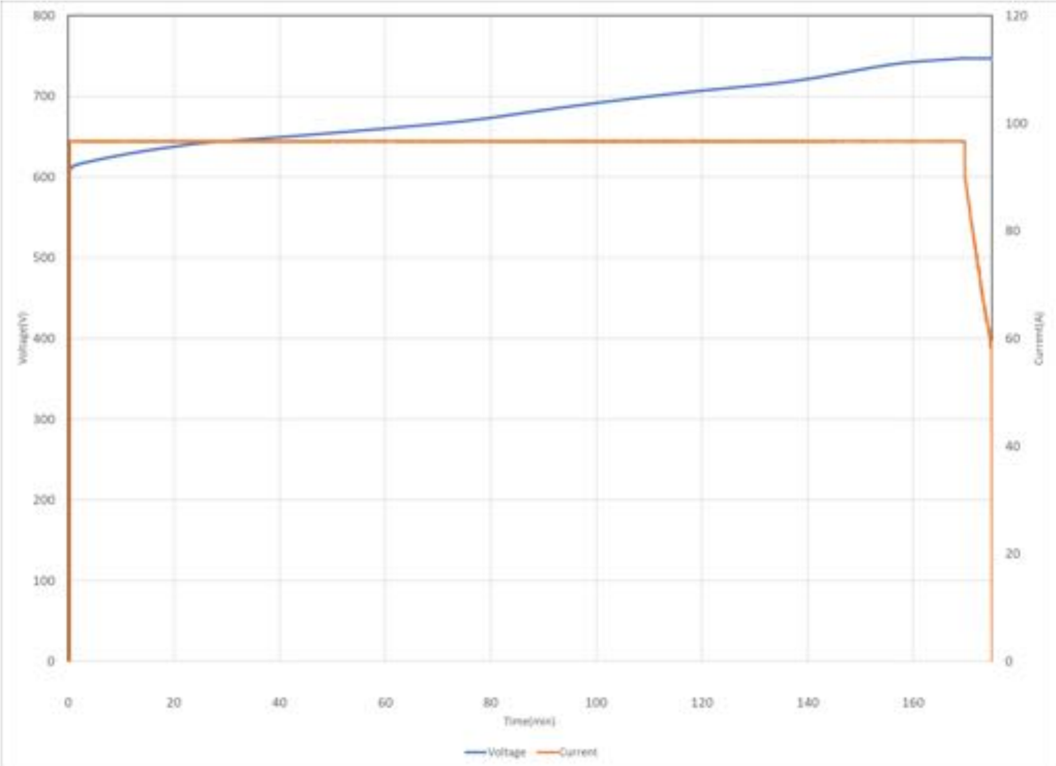


Figure A3 – Module 6 to 9 and Module 11, 12 charge profile, connected in series

Attachment B: BESS (including module and any integral fire detection and suppression systems) Construction Photos/Diagrams - (*Pages **33** through **34***)

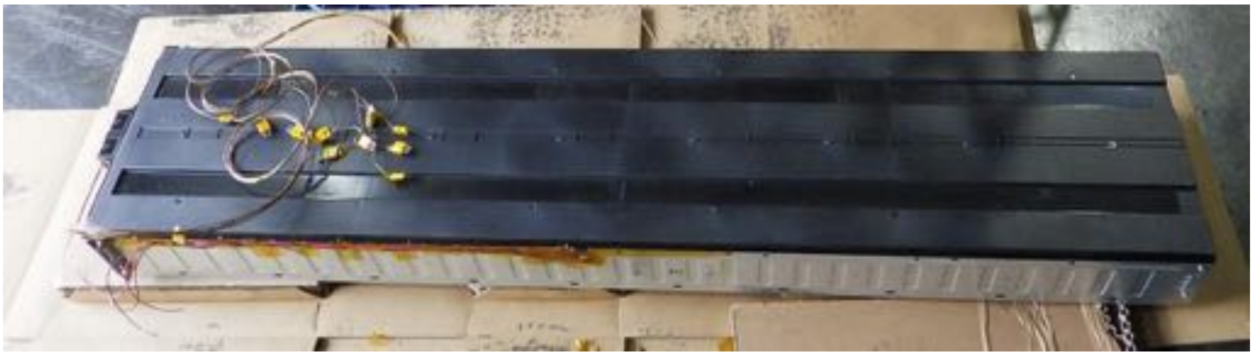


Figure B1 – Photo of the initiating module

Figure B2 – Photo of Unit and BCP Box

Figure B3 – Dummy units populated on the other side of the container
(Initiating unit in red box and Target 1, 2 in blue box)

Figure B4 – Photo of the container

Attachment C: : BESS and Equipment Instrumentation and Test Installation Layout Photos/Diagrams - (*Pages **35** through **40***)

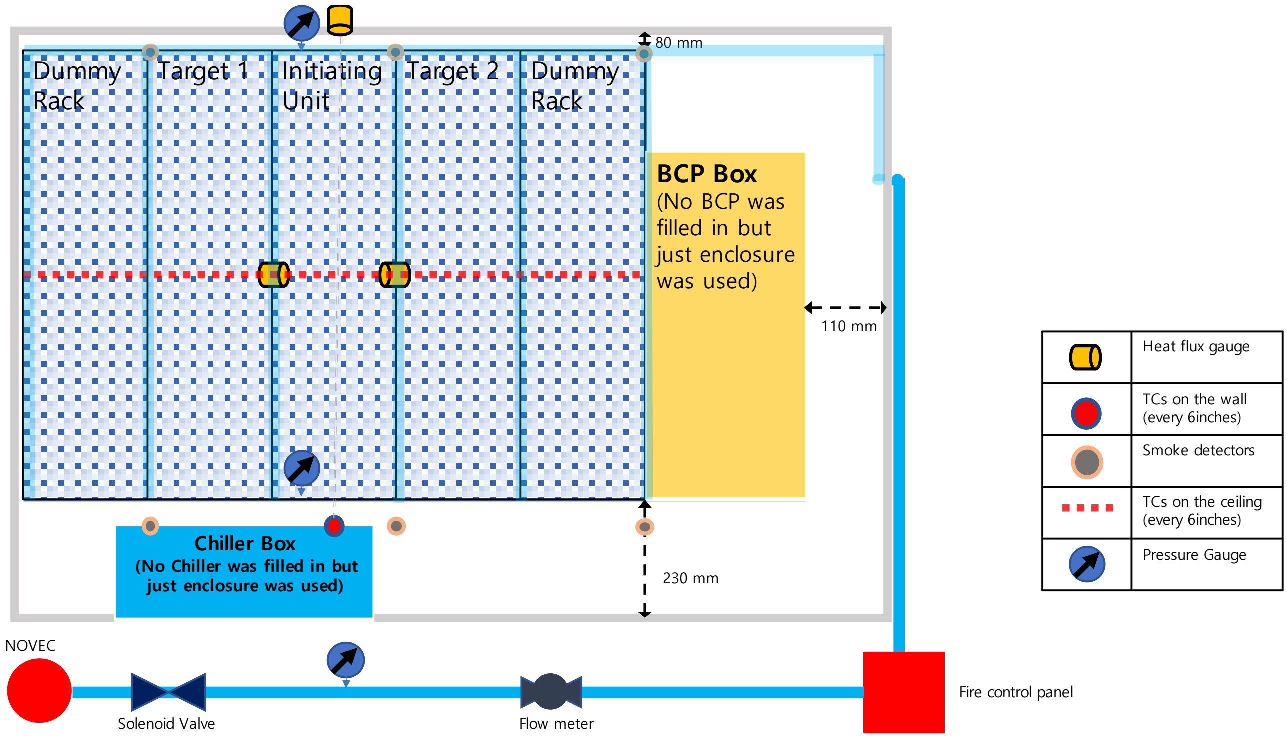


Figure C1 - Overall Layout Diagram

Table C1 – Test configuration

Test Configuration	
Clearance between Initiating Unit and Target Unit 1	0 mm
Clearance between Initiating Unit and Target Unit 2	0 mm
Clearance between Initiating Unit and the Door, front side of Unit	233 mm
Clearance between Initiating Unit and the back container enclosure, rear side of Unit	80 mm
Clearance between Initiating Unit and the side wall	110 mm (side of BCP) 0 mm (opposite side of BCP)

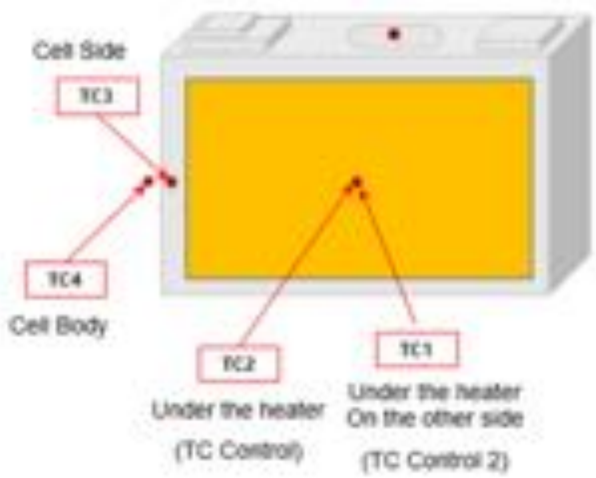


Figure C2 – Initiating cell thermocouples locations

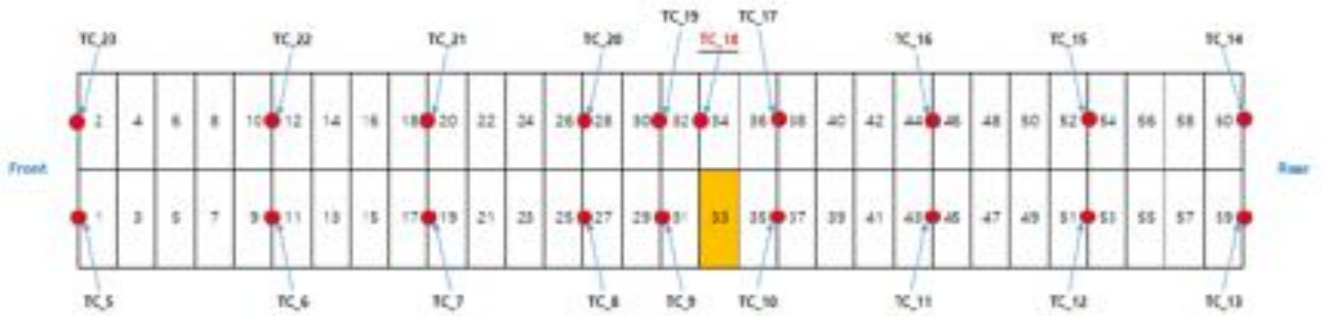


Figure C3 – Location of initiating cell and additional thermocouples within module

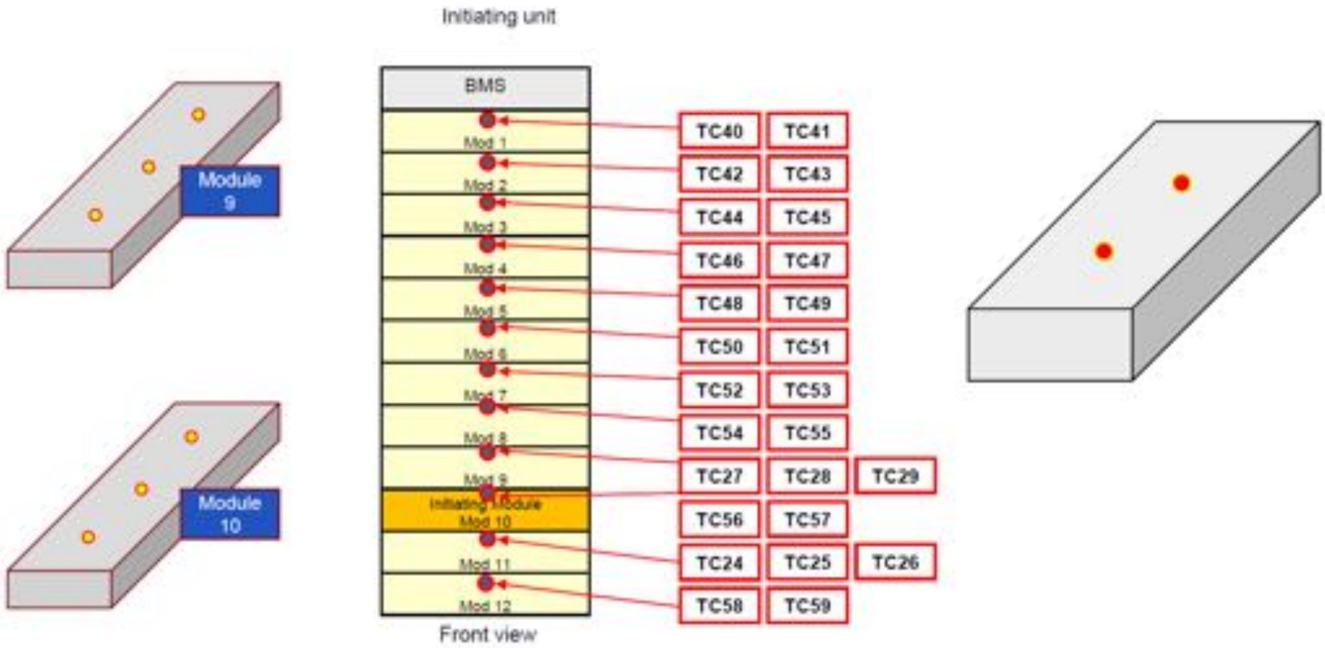


Figure C4 – Thermocouple locations for non-initiating modules in the initiating Unit

Figure C5 – Thermocouple and Heat flux locations in Target Unit 1

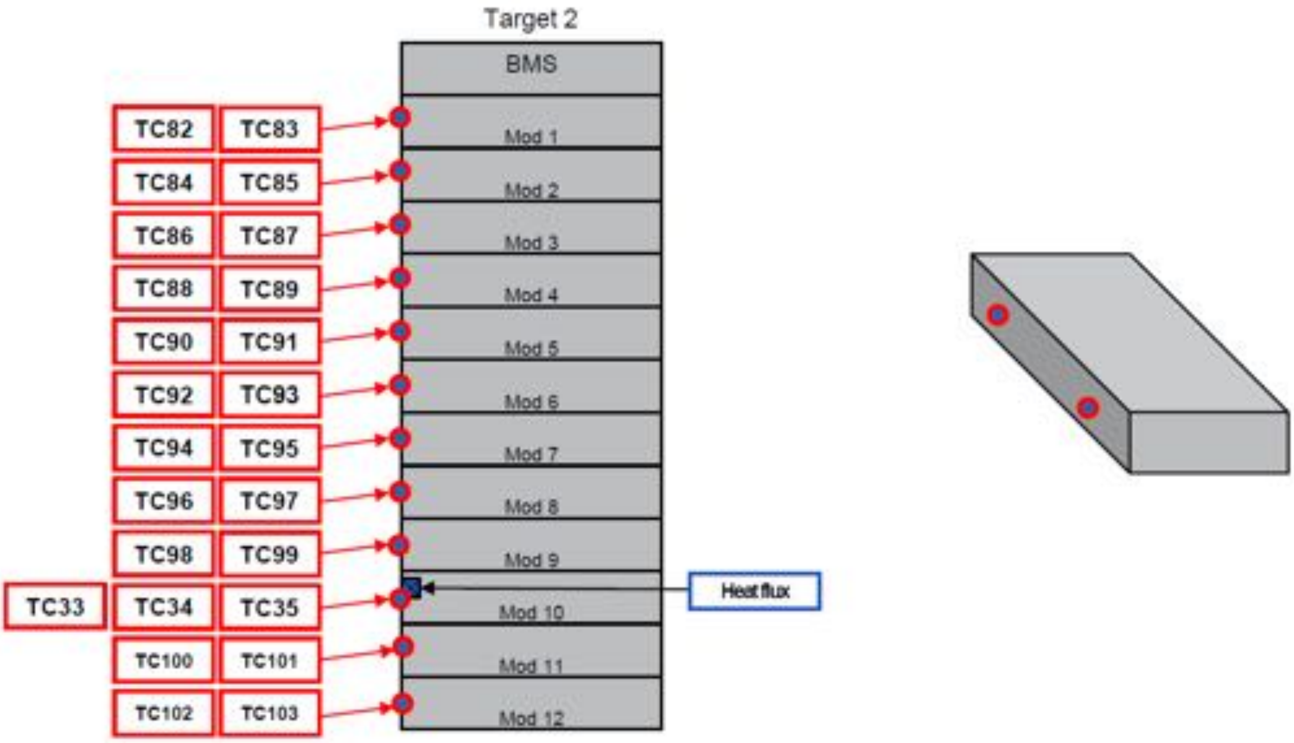


Figure C6 – Thermocouple and Heat flux locations in Target Unit 2

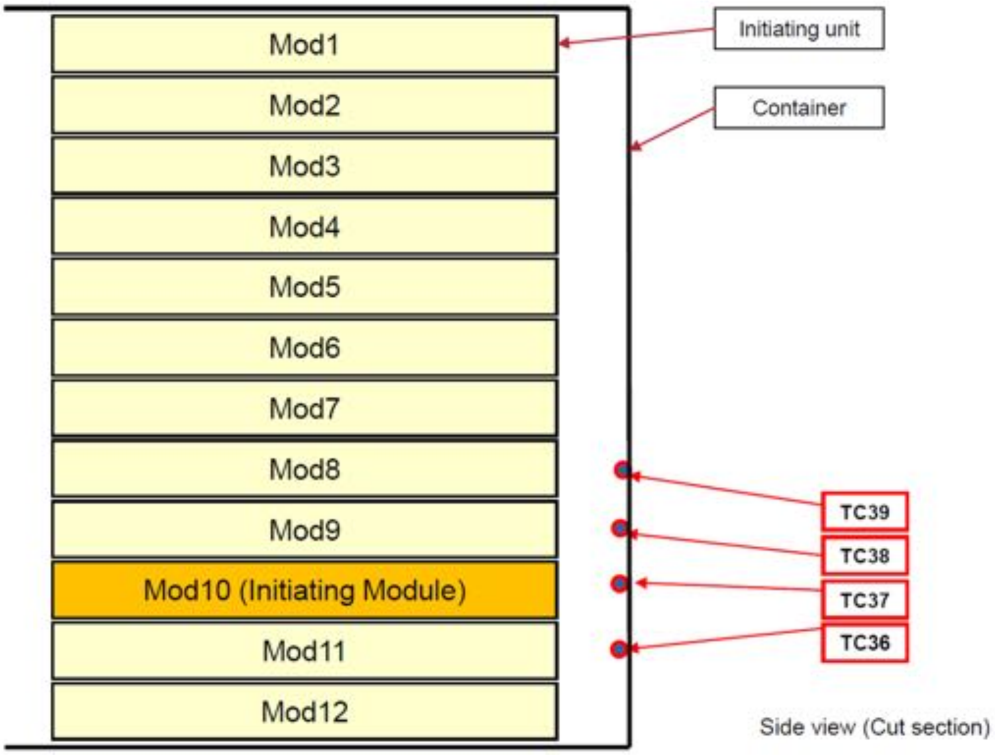


Figure C7 – Thermocouple locations at the back of the initiating unit

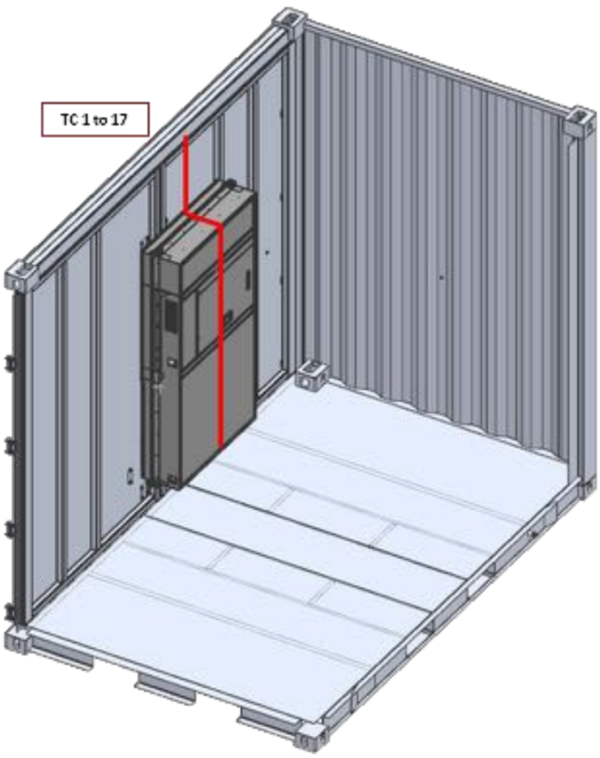


Figure C8 – Thermocouple locations on the front door of the container, aligned with the initiating cell location

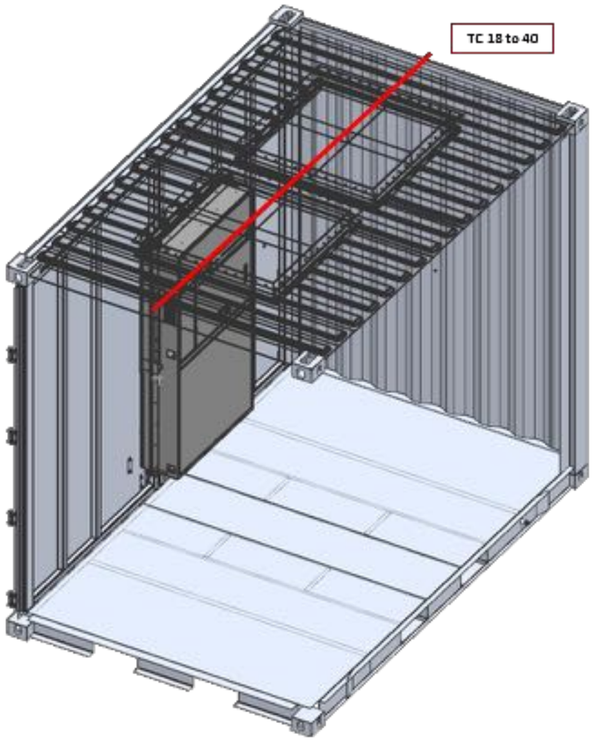


Figure C9 – Thermocouple locations on the ceiling of the container[12]

12 Thermocouples (K-type) were instrumented every six inches in accordance with 10.3.5

Figure C10 – Photo of the heat flux gauge (in the yellow circle) to account for the egress path and the pressure gauge to measure a potential explosion pressure (in the blue circle)

Attachment D: Temperature Profiles and Heat Flux Measurements During Testing (Initiating Cell and Module, Target Modules, Wall Surfaces, etc. - (*Pages **41** through **44***)

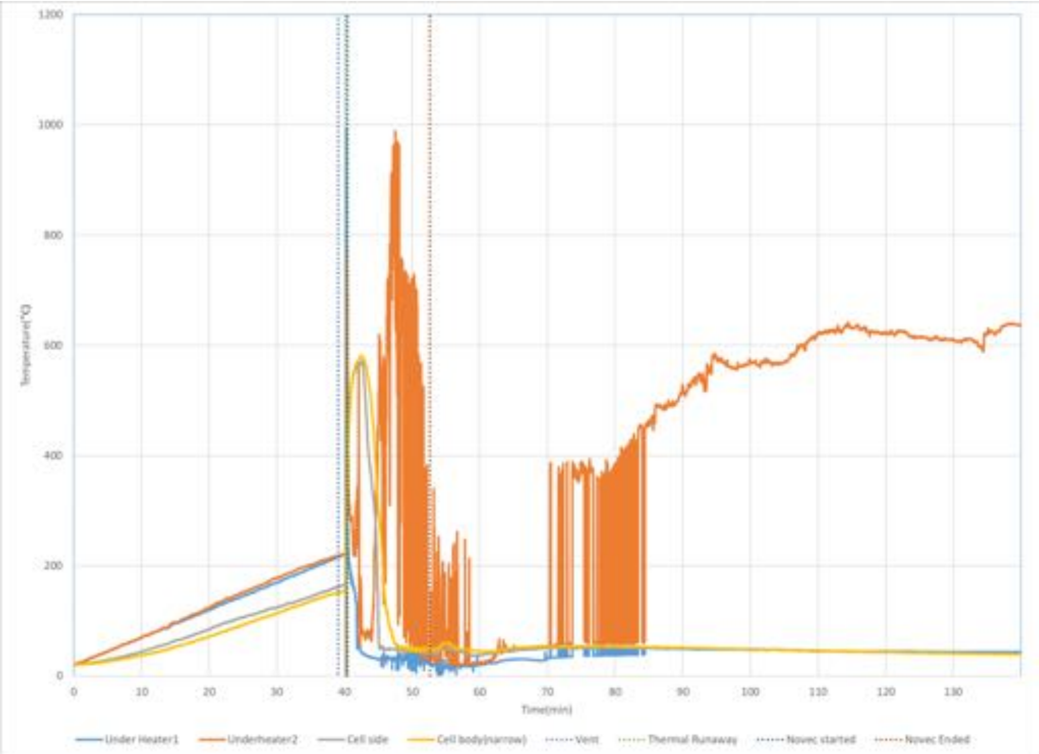


Figure D1 – Surface temperatures measured on the initiating cell during the test

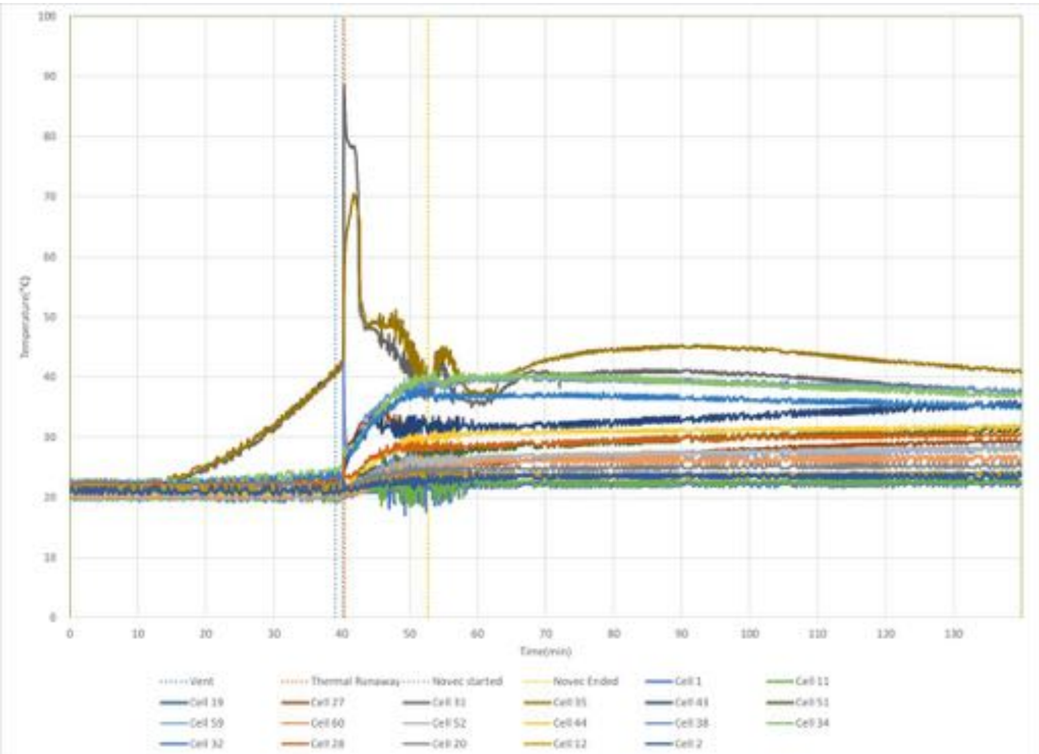


Figure D2 – Temperature measurements on the instrumented non-initiating cells in the initiating module

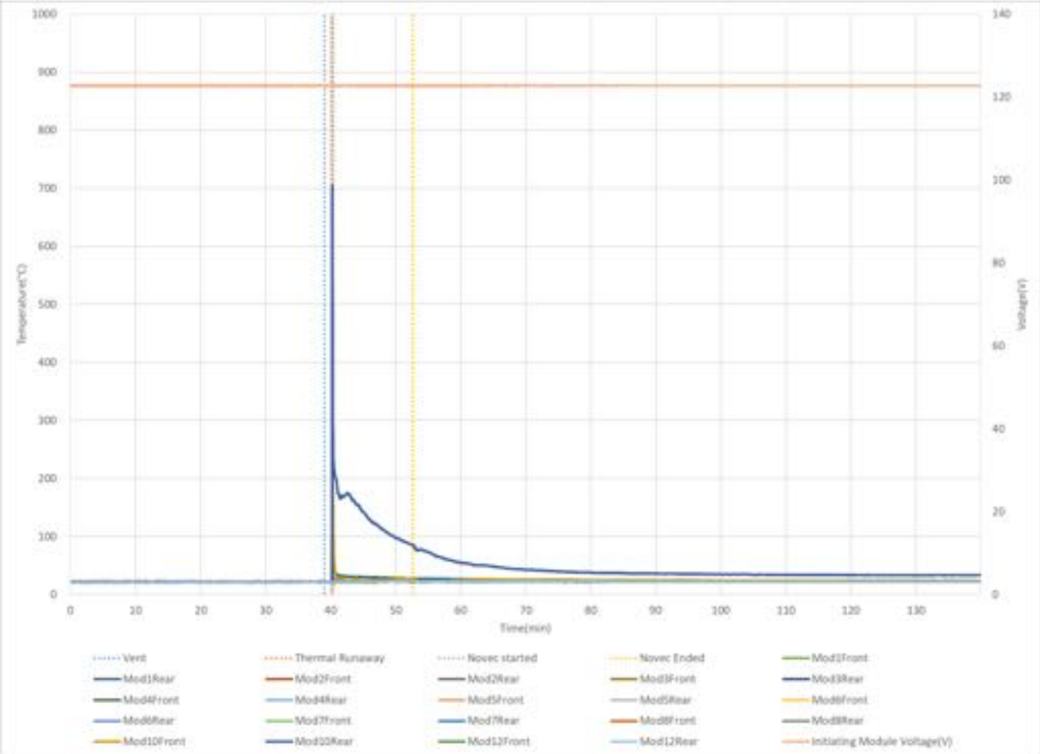


Figure D3 – Temperature and voltage measurement on the modules in the initiating unit

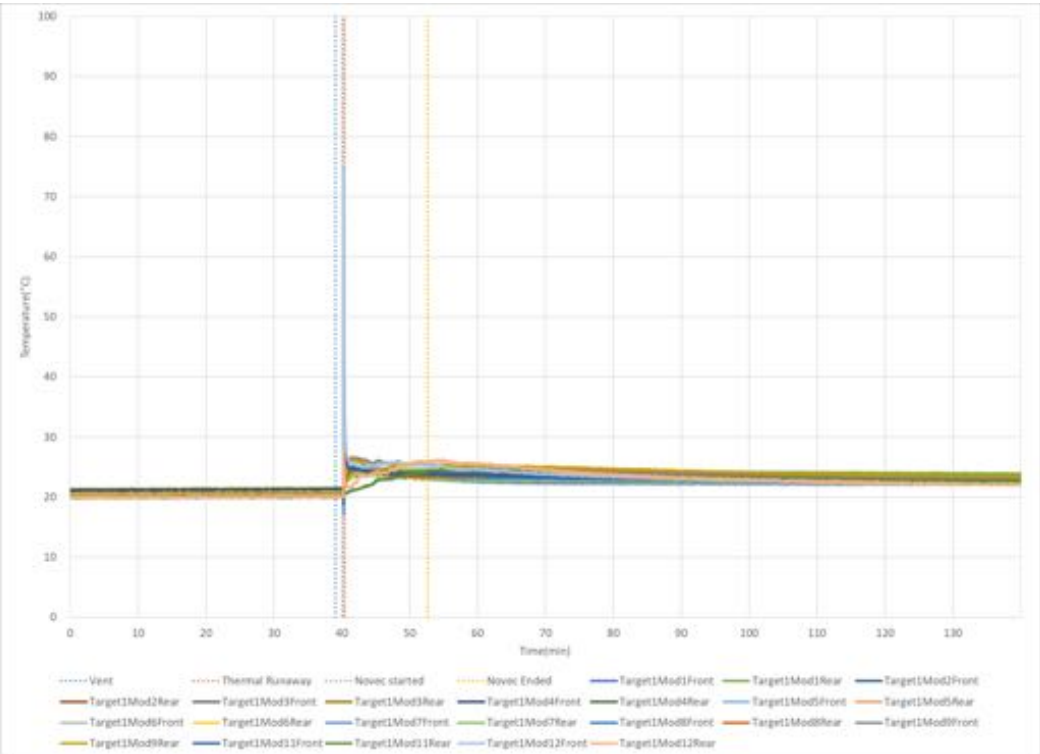


Figure D4 – Temperature measurement on the modules in the target unit 1

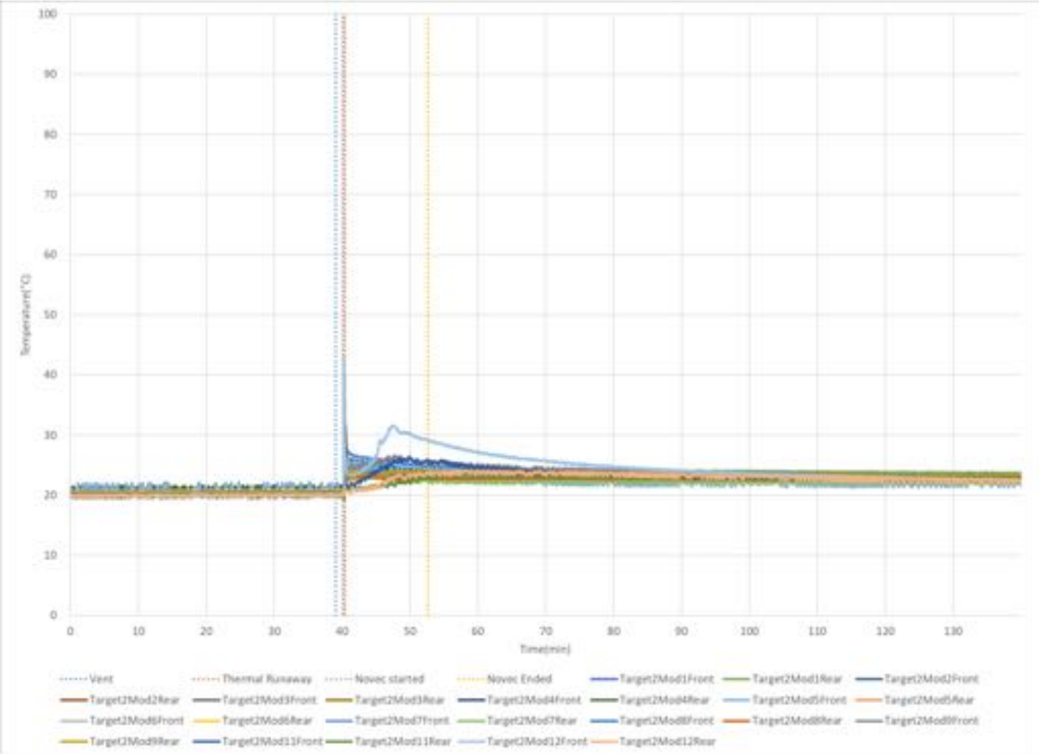


Figure D5 – Temperature measurement on the modules in the target unit 2

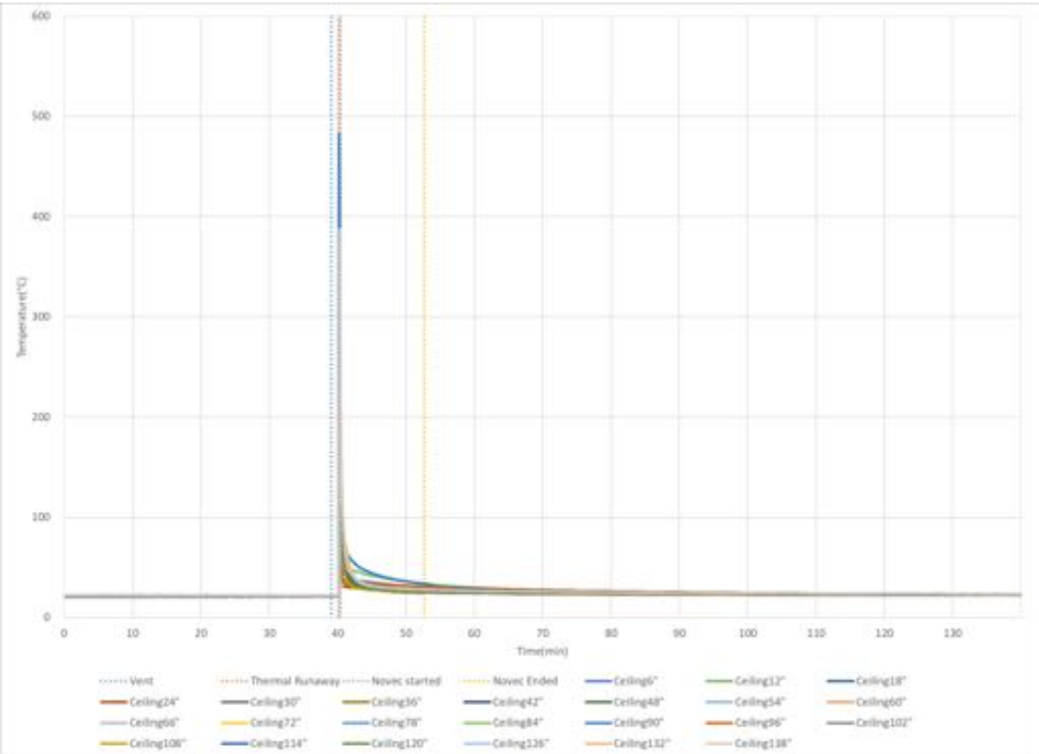


Figure D6 – Temperature measurement on the ceiling of the container

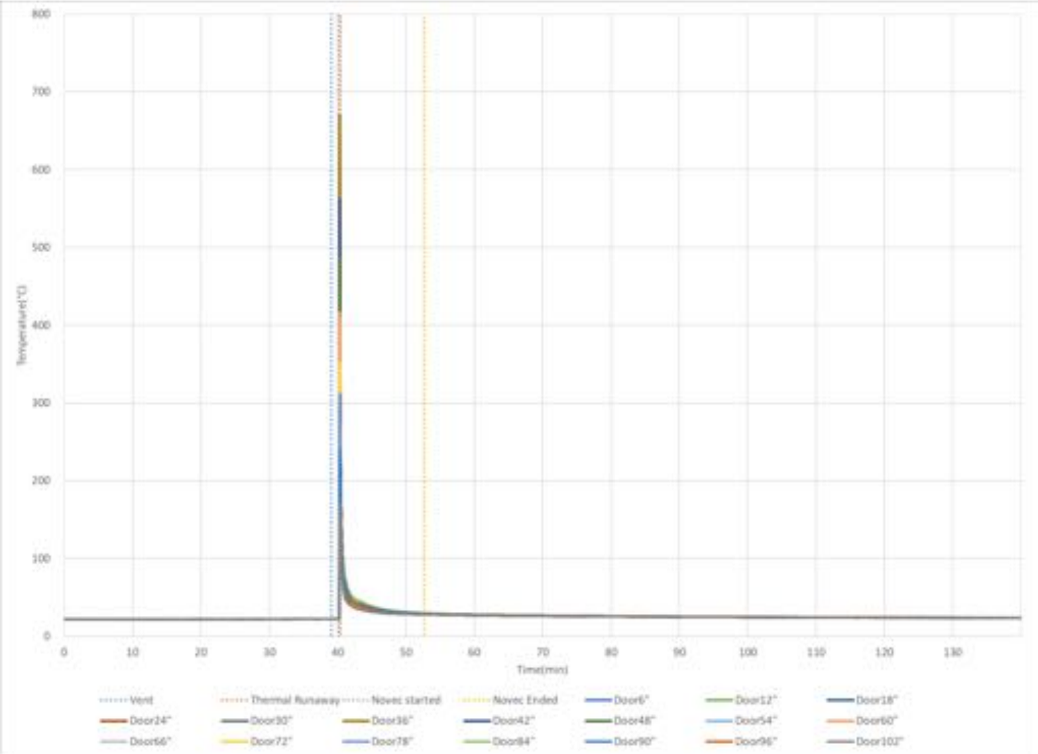


Figure D7 – Temperature measurement on the inside of the door of the container, located in front of the initiating unit

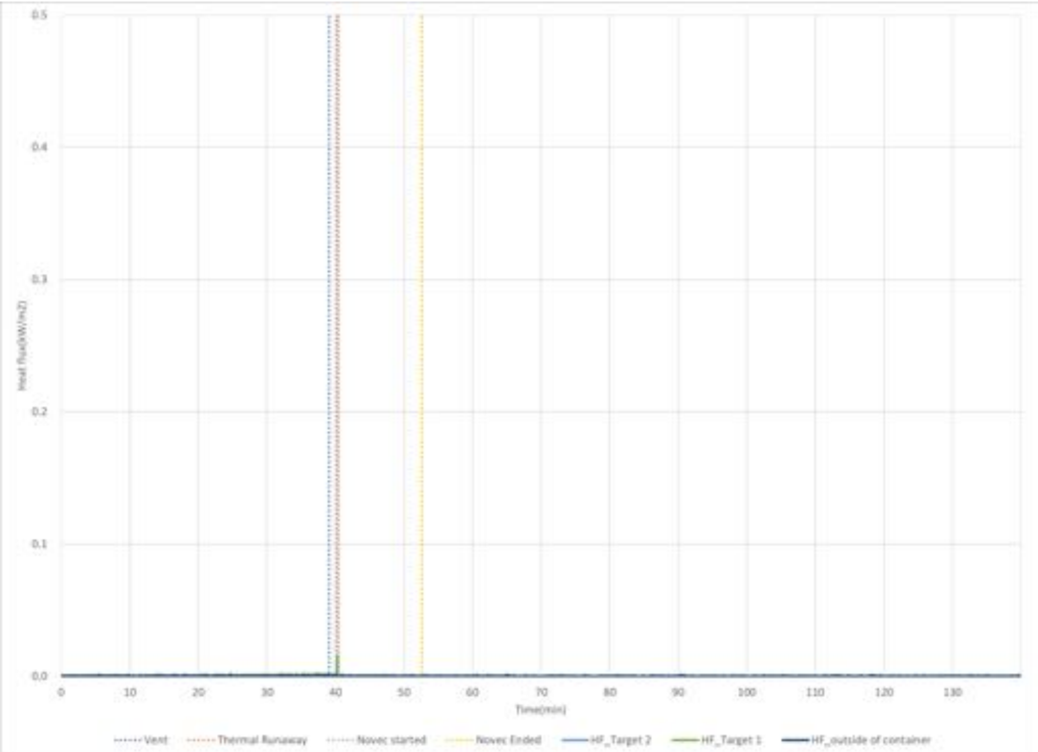


Figure D8 – Heat flux measurement for target units and outside the container

Attachment E: BESS Unit Testing and Post Testing Photos - (*Pages **45** through **49***)

 (a) Test Start [00:00:00]	 (b) Thermal runaway inside of the container [00:40:13]
 (c) Ignition flame observed [00:40:15]	 (d) Lost camera visibility [00:40:23]

 (e) The First Smoke detection [00:40:24]	 (f) The second Smoke detection and Novec release [00:40:26]
 (g) Recorded last snapshot [00:55:00]	 There was an error in recording located inside of container, some of snapshot of video were not available. (h) Test end [02:19:57]

Figure E1 – Photo of the units after the test

Figure E2 – Photo of the door with Chiller box enclosure and thermocouple arrays after the test

Figure E3 – Photo of the top of the initiating module after the test

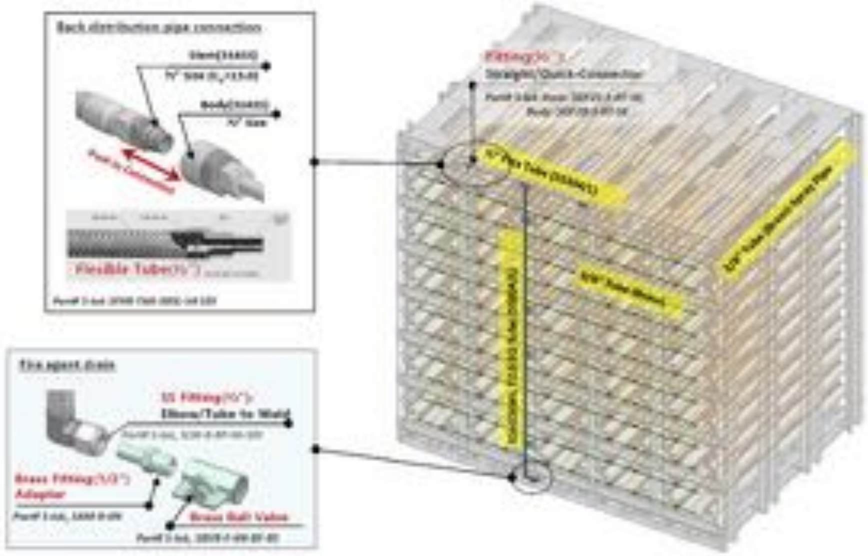
Figure E4 - Photo of the side of the initiating module after the test

Figure E5 - Photo of the top and the bottom of the initiating module after the test

Attachment F: Fire suppression system and deflagration mitigation system - (*Pages **50** through **55***)

Frame design of Direct Injection

- 360S Configuration, consists of liquid cooling piping at the front and Direct Injection piping at the back



Method of Direct Injection

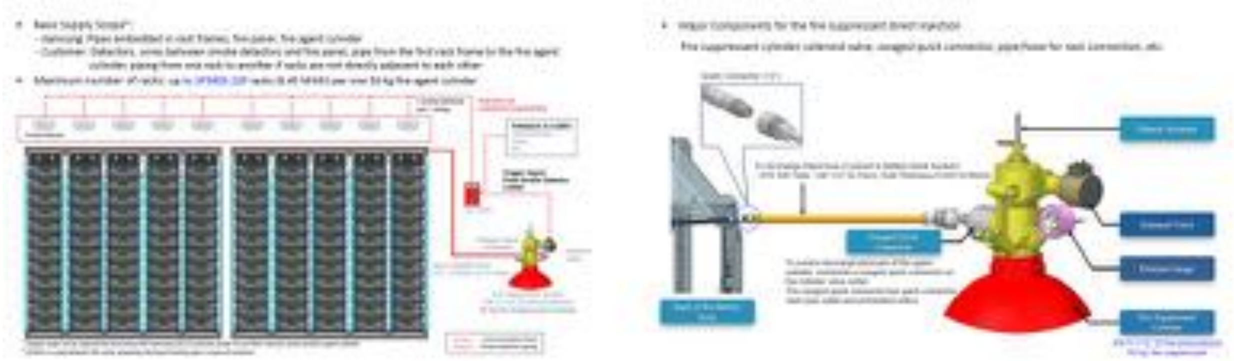


Figure F1 – Principle of the direct injection system, as per Samsung SDI

Figure F2 – Photo of Novec 1230 Cylinder

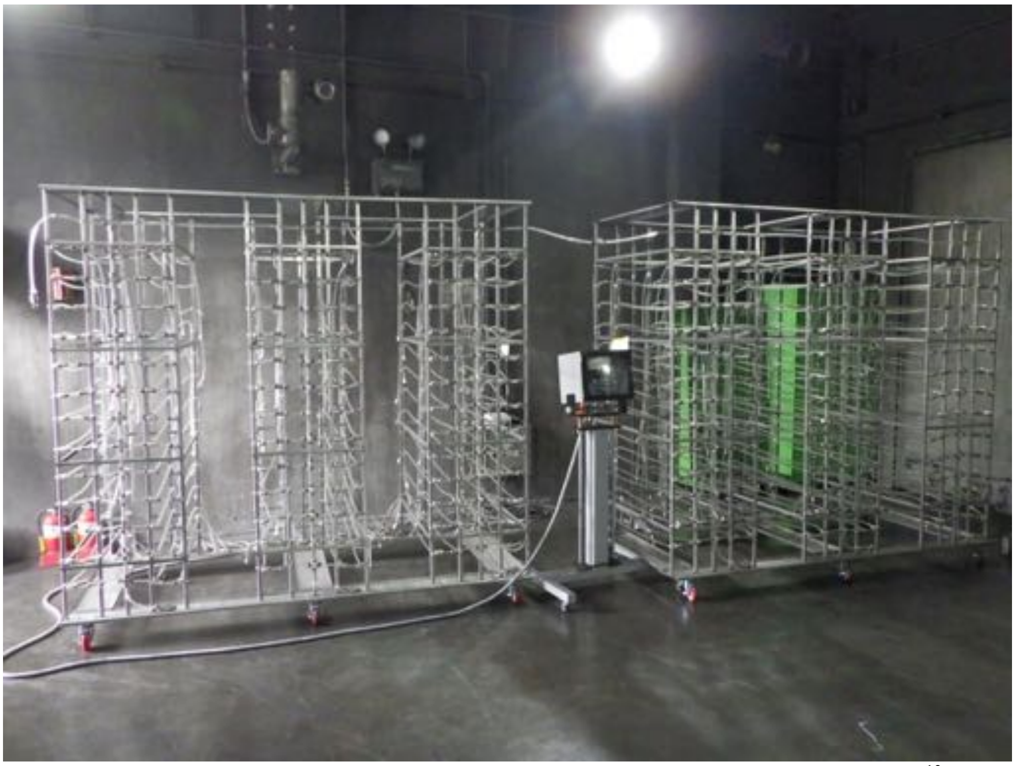


Figure F3 – Photo of dummy pipe racks to account for the pressure drop[13]

Figure F4 – Photo of the hoses going through the container wall and the urethane seal

[13] The dummy pipe racks were designed by Samsung to simulate the pressure drop of the suppressant to account for the case where more racks could be installed. The dummy racks were installed between the downstream of the cylinder and the container.

Figure F5 – Photo of the smoke detector installed above the rack

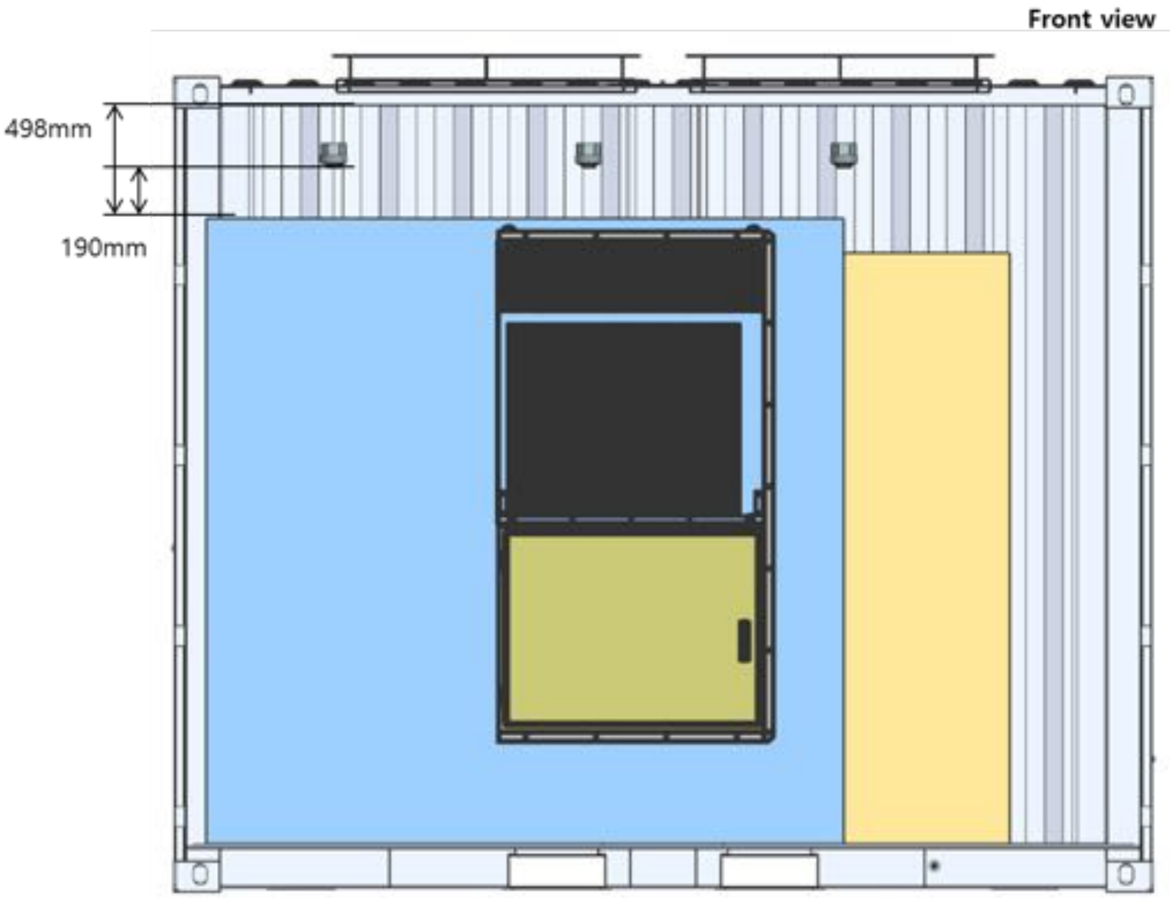


Figure F6 – Layout of the smoke detector

Figure F7 – Photo of the deflagration panel on the ceiling (taken from out side of the container)

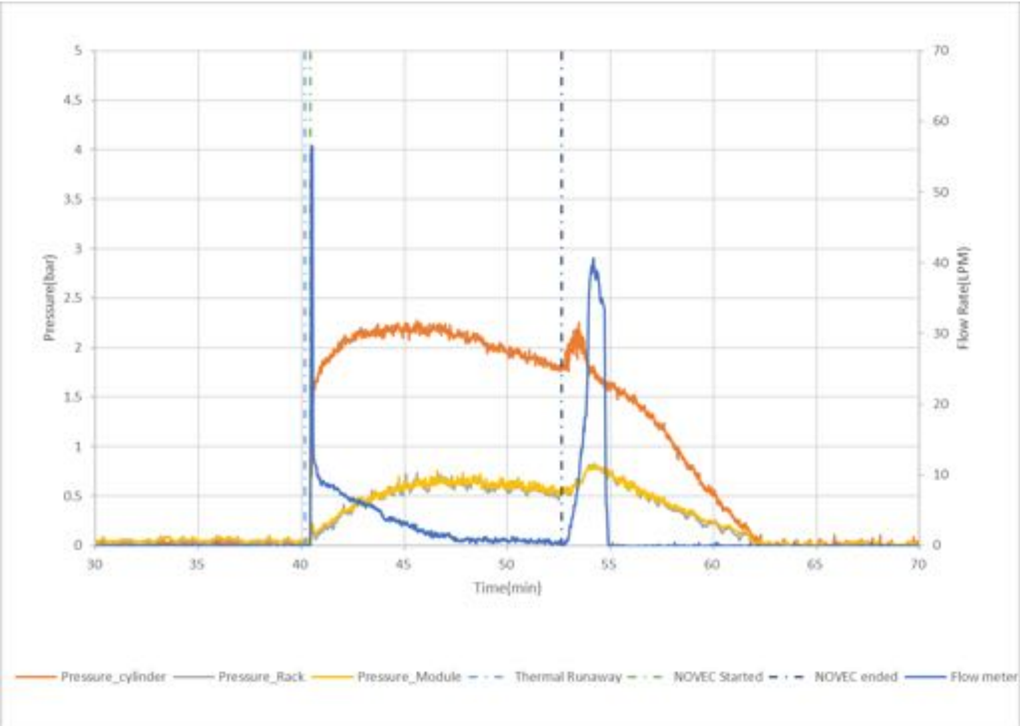


Figure F8 – Pressure and flow rate measurements on the cooling system

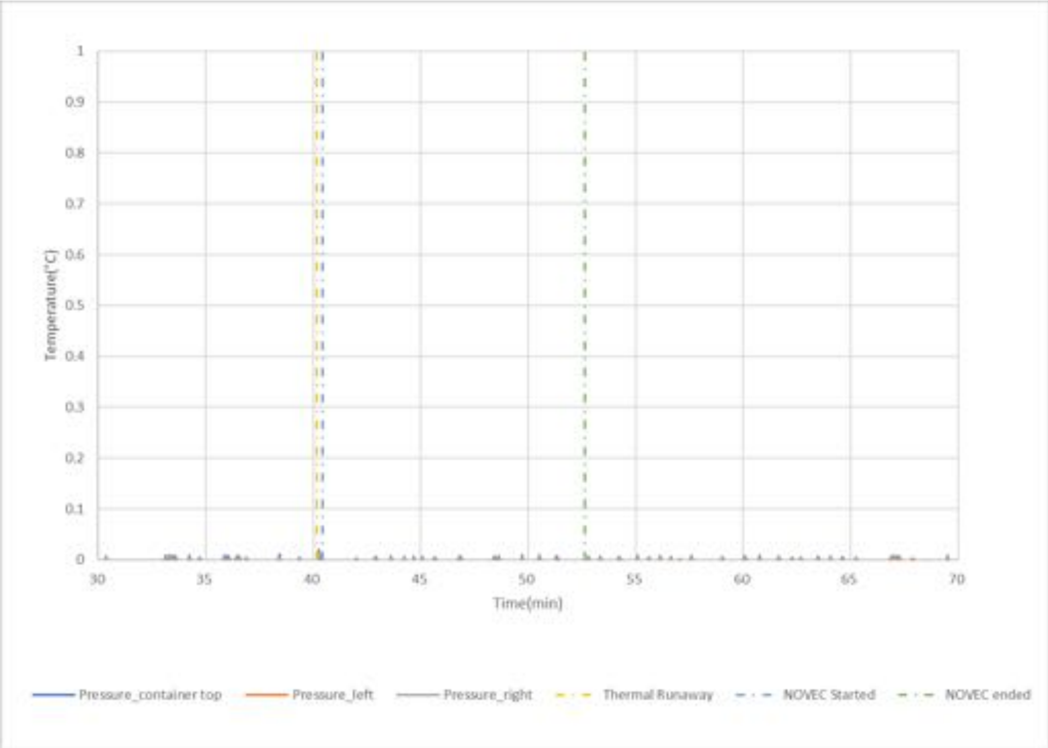


Figure F9 – Pressure measurements on the container

Attachment G: Certification requirement decision of container system BESS in UL9540A - (*Pages **56** through **61***)

UNDERWRITERS LABORATORIES INC. CERTIFICATION REQUIREMENT DECISION

This Certification Requirement Decision is prepared by UL LLC. It is normative for the applicable UL Product Certification Program(s); however, it is currently not part of the UL Standard(s) referenced below.

Product Category (CCN): AACD
Standard Number: UL 9540A
Standard Title: Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems
Edition Date: November 12, 2019
Edition Number: 4
Section / Paragraph Reference: Revised: 9.1.1, 10.1.2, 10.3.1, 10.4.1, 10.7.1
New: 4.4.1, 9.1.2.1, 10.1.1, 10.2.3, 10.3.16, 10.5.9, 10.6.2, 10.8.2
Subject: Test Approach for Multi-Battery Rack Container BESS

DECISION:

4.4.1 CONTAINER SYSTEM (BESS) – For the purposes of this standard, a large, enclosed BESS with multiple battery system racks that may or may not be a walk-in system and that may contain integral fire detection and suppression systems and may include integral deflagration or explosion protection.

9.1.1 The unit level test shall be conducted with BESS units installed as described in the manufacturer's instructions and this section. Test configurations include the following:

a) Indoor floor mounted non-residential use BESS;

b) Indoor floor mounted residential use BESS;

c) Outdoor ground mounted non-residential use BESS;

d) Outdoor ground mounted residential use BESS;

e) Indoor wall mounted non-residential use BESS;

f) Indoor wall mounted residential use BESS;

g) Outdoor wall mounted non-residential use BESS;

h) Outdoor wall mounted residential use BESS; and

i) Rooftop and open garage non-residential use BESS installations.; and

j) Container system BESS.

9.1.2.1 For a container system BESS including those intended for outdoor installation only, the unit level test shall be in accordance with the indoor floor mounted unit level test using the battery system racks as the test units and with the test installation set up in accordance with the installation layout within the container.

10.1.1 General

10.1.1 The installation level test method assesses the effectiveness of the fire and explosion mitigation methods for the BESS in its intended installation. The installation level testing does not apply to residential use BESS.

a) Test Method 1 – "Effectiveness of sprinklers" is used to evaluate the effectiveness of sprinkler fire protection and explosion mitigation methods installed in accordance with code requirements.

b) Test Method 2 – "Effectiveness of fire protection plan" is used to evaluate the effectiveness of other fire and explosion mitigation methods (e.g., gaseous agents, water mist systems, combination systems).

c) Test Method – Container System BESS installation level test

10.1.2 Installation level testing is not appropriate for units only intended for outdoor use or residential use. Container system BESSs as defined in this standard, although typically for outdoor use installations, are included in the installation level test as the container, which may include integral fire detection and suppression and integral explosion or deflagration protection represents a type of installation.

10.2.3 For container system BESS, the units utilized for initiating and target units are the battery system racks that are installed within the container. The container system BESS shall be populated with one initiating unit chosen as the location within the container that may result in worse case results and target units installed around and across the initiating BESS representative of the intended container layout. The fire detection and suppression systems and deflagration/explosion protection systems if provided for the container installation, shall be installed in the system for the test. Any wiring within the container either intended to be installed above the units or along them horizontally, that can be a source of fire spread, should be included in the container for the test. Equipment mounted to openings in the container that may impact air flow and therefore test results, should be included in the installation for the test. Internal equipment such as a power conditioning/conversion system or switchgear, can be represented by their enclosures or other simulation means for temperature measurement purposes.

10.3.1 For BESS units with a height of 2.44 m (8 ft) or less, the test shall be conducted in a 6.10 × 6.10 × 3.05-m (20 × 20 × 10-ft) high test room with one open 1.22 × 2.13-m (4 × 7-ft) high doorway or a room representative of the installation configuration as specified by the manufacturer. The ~~largest~~ smallest test room anticipated by the manufacturer for BESS deployments, including footprint and ceiling height, shall be tested. For BESS units taller than 2.44 m (8 ft), the ceiling height shall be increased to be at least 0.61-m (2-ft) higher than the BESS units under test. The explosion mitigation methods shall be installed in the test installation in accordance with the manufacturer's specifications. Pressure sensors shall be installed as close to the deflagration vents as possible to determine the maximum pressure developed during the test. The pressure shall be measured with frequency of at least 5000 samples per second.

10.3.16 Test Method - Container System BESS Installation Level (Test Method 1)

10.3.16.1 A container system BESS that utilized sprinkler system fire suppression shall be tested in accordance with 10.3 except instead of the test room, the actual container shall be used as the test room.

10.3.16.2 Temperatures on walls, ceiling and target modules shall be measured in accordance with 10.3.5, 10.3.6 and 10.3.11.

10.3.16.3 The installation shall include any exposures representing major components (e.g. battery system racks, power conditioning system, HVAC, etc.) installed within the container system. Temperatures shall be measured on those exposures with combustible construction besides walls, ceiling and target modules. Temperatures on exposures with large surfaces (height > 12 inches) shall be measured similar to the approach used for measuring temperatures on walls. Temperatures on exposures with small surfaces (height ≤ 12 inches) shall be measured on at least one location where the greatest temperature is expected to be achieved. The exposure can be represented by the equipment enclosure or a wall or other means placed in a similar manner to represent the location and layout of the major component exposures.

10.4.1 The report on installation level testing shall include the following:

a) Unit manufacturer name and model number (and whether compliant with UL 9540 or UL 1973) and the container system BESS manufacturer name and model number (and whether compliant with UL 9540);

b) Number of modules in the initiating BESS unit;

c) The construction of the initiating BESS unit per 5.3, and the number of battery system racks and overall construction within the container for a container system BESS;

d) Module voltage(s) of initiating BESS corresponding to the tested SOC;

e) The thermal runaway initiation method used;

f) Diagram and dimensions of the test setup including location of the initiating and target BESS units, and the locations of walls and ceilings, and location of included internal target components in the container system BESS (e.g. target integral power conditioning system or integral switch gear enclosure, etc.);

g) Location of initiating module within the BESS unit;

h) Separation distances from the initiating BESS unit to (e.g. distances A and C in Figure 10.1);

i) Separation distances from the initiating BESS unit to target BESS units (e.g. distances D and E in Figure 10.1);

j) Distances of the flame indicator (if used) with respect to the BESS (e.g. distances A and B in Figure 10.2);

k) Maximum temperature at the ceiling or, for a container BESS, maximum temperature of the container ceiling;

l) Distance of fire spread within the flame indicator or indication of fire spread through wiring in a container system BESS;

m) The maximum wall surface and target BESS unit temperatures achieved during the test and the location of the measuring thermocouple;

n) The maximum incident heat flux on target wall surfaces and target BESS units;

o) Voltages of initiating BESS;

p) Total number of sprinklers that operated and length of time the sprinklers operated during the test;

q) Gas generation and composition data, if measured;

r) Observation of flaming outside of the test room or container and the length and location of the external flaming;

s) Observation of installed explosion/deflagration protection operation and maximum pressures measured at deflagration vents;

ts) Observation of flying debris or discharge of gases;

ut) Observation of re-ignition(s) from thermal runaway events;

vu) Observations of the damage to;

1) The initiating BESS unit;

2) Target BESS units; and

3) Adjacent walls;

wv) Photos and video of the test;

xw) Fire protection features/detection/suppression systems within unit; and

y) Explosion and deflagration protection; and

zx) Sprinkler K-factor, RTI, manufacturer and model, number of sprinklers and layout and length of time of operation of the sprinklers.

10.5.9 Test Method - Container System BESS Installation Level (Test Method 1) - Performance

10.5.9.1 The performance of container system BESS subjected to installation test method 1, is the same as 10.5.2 through 10.5.8 except as follows:

a. Temperatures on any combustible construction within the container including target components shall not exceed a temperature rise of 97°C (175°F) above ambient.

b. There shall be no flaming outside of the container if intended for indoor installation.

10.6.2 Test Method - Container System BESS Installation Level (Test Method 2)

10.6.2.1 A container system BESS that utilizes an alternative fire suppression system shall be tested in accordance with 10.6 except as noted 10.6.2.2 through 10.6.2.5.

10.6.2.2 The actual container shall be used as the test room instead of the test room described in 10.3.1.

10.6.2.3 The installation shall include any targets representing any major components (e.g. power conditioning system) installed within the container system and temperatures shall be measured on these targets similar to the approach used for measuring temperatures on walls. The target can be represented by the equipment enclosure or a wall or other means placed in a similar manner to represent the location and layout of the components.

10.6.2.4 The walls outside of the container are not required to be instrumented, however, container wall surface temperatures shall be measured in vertical array(s) at 304-mm (12-in) intervals for the full height of the instrumented wall sections using No. 24-gauge or smaller, Type-K exposed junction thermocouples. The thermocouples for measuring the temperature on wall surfaces shall be horizontally positioned in the wall locations anticipated to receive the greatest thermal exposure from the initiating BESS unit.

10.6.2.5 Heat flux at the walls may be measured with the sensing element of at least two water-cooled Schmidt-Boelter or Gordon gauges at the surface of the container wall:

a) Both are collinear with the vertical thermocouple array;
b) One is positioned at the elevation estimated to receive the greatest heat flux due to the thermal runaway of the initiating module; and
c) One is positioned at the elevation estimated to receive the greatest heat flux during potential propagation of thermal runaway within the initiating BESS unit.

10.7.1 The report on installation level testing shall include the following:

a) The report information in 10.4.1 items (a) – (zw), and (y and zw) if applicable;

b) Fire protection features/detection/suppression systems within installation; and

c) Length of time of operation of the clean agent, or other suppression system in addition to any sprinklers used.

10.8.2 Test Method - Container System BESS Installation Level (Test Method 2) - Performance

10.8.2.1 See 10.5.9 for performance criteria for a container system.

STANDARD NUMBER: UL 9540A -8-

RATIONALE FOR DECISION:

UL 9540A does not currently provide sufficient detail for testing large multi-battery rack container BESS. These systems should first conduct the unit level test of the battery rack layout representative of how they are installed in the container indoors under the calorimeter to obtain the off gassing data including the battery fire behavior during testing. Depending upon the results of this unit level test, an installation level test can be conducted with the racks installed within the container representative of the installation and how they were tested in the unit level with the supplied fire suppression and deflagration protection provided.

In this way the container becomes the "test room" similar to how we would conduct the installation test in a built test room representative of an indoor installation. It also provides sufficient data to understand the hazards that may be associated with the container BESS design without resulting in the testing hazards associated with trying to run the test on a completely populated container BESS.

Exhibit 2

SANTA FE COUNTY

Santa Fe County Fire Department

Fire Prevention Division

Conditional Use Permit Plan Review

Date	October 11, 2024	**Reviewer**	J. Blay
Project Name	Rancho Viejo Solar Project in Santa Fe County, New Mexico		
Project Location	4152 NM HWY 14 Santa Fe, NM 87508		
Description	A 96-megawatt (MW) solar facility, a 48-megawatt (MW) battery energy storage system (BESS), a substation, a generation tie-in line, an access road, an aboveground water storage tank, and an operations building		
Applicant Name	Joshua Mayer	**Case Manager**	Jessica Gonzales
Applicant Address	282 Century Place, Suite 2000Louisville CO 80027	**County Case #**	24-5200
Applicant Phone	(720) 514-2957	**Fire District**	Turquoise Trail

This conditional use permit application is deemed complete by the Santa Fe County Fire Department based on the following considerations:

Atar Fire has performed a detailed review of the following project documents provided to them electronically:

- *'SRA01b_PreIncidentPlan_EIR_AppxB' (Pre-Incident Plan)*
- *'SRA01g_FirstResponder_EIR_AppxG' (Emergency Response Plan)*
- *'SRA01h_PreliminaryHMAredacted_EIR_AppxH' (Hazard Mitigation Analysis)*
- *'11_SiteDevelopmentPlan_CUP_RanchoViejo' (Project Drawings)*
- *'Proprietary_CEN-E5S Enclosure Deflagration Test Report – 522*
- *'Proprietary_CEN-E5S Enclosure UL 9540A Test report – 523'*
- *'Proprietary_DRAFT_Report_TR_230499RECO01_CEN_UL9540'*
- *'Proprietary_E5_UL9540A Cell Report 127'*
- *'Proprietary_E5S UL 9540A Module Test Report 128'*
- *'Proprietary_E5S 9540A Unit Test Report – 129'*
- *'Proprietary_Preliminary_Dispersion and Deflagration Modeling Progress Report'*
- *'Proprietary_Vigilex_CEN-E5S_NFPA68_DesignCalcs_OD730636AV02'*

The documents were reviewed in accordance with the following Codes and Standards as adopted in Santa Fe County, New Mexico:

- *International Fire Code, 2021 Edition*
- *NFPA 855, Standard for the Installation of Stationary Energy Storage Systems, 2023 Edition*

Where other Codes and Standards are referenced in applicable sections of the aforementioned Codes and Standards, they have been reviewed to the extent they apply.

Based on Atar Fire's detailed review letter, both Atar Fire and Santa Fe County Fire Department have concluded that a sufficient level of information has been provided to validate the issuance of a Conditional Use Permit, as it pertains to the reviewed fire and life safety codes. However, all of the items in this review letter must be satisfactorily addressed prior to commissioning of the facility. Atar Fire review does not constitute all possible recommendations associated with this installation, as deferred submittals and additional documentation is required prior to the commissioning of this facility, should a CUP approval be granted.

Atar Fire review letter is attached.

Reviewed by:

Jaome R. Blay

Santa Fe County Fire Marshal

October 11, 2024

Date

ATAR FIRE

October 9, 2024

Delivered by Email

Mr. Jaome Blay
Fire Marshal
Santa Fe County
jblay@santafecountynm.gov

RE: Atar Fire Review of AES CUP Application Resubmittal (Project Name: Rancho Viejo Solar Project)

Dear Mr. Blay,

Atar Fire has performed a review of the following project documents provided to us electronically:

- 'SRA01b_PreIncidentPlan_EIR_AppxB' (Pre-Incident Plan)
- 'SRA01g_FirstResponder_EIR_AppxG' (Emergency Response Plan)
- 'SRA01h_PreliminaryHMAredacted_EIR_AppxH' (Hazard Mitigation Analysis)
- '11_SiteDevelopmentPlan_CUP_RanchoViejo' (Project Drawings)
- 'Proprietary_CEN-E5S Enclosure Deflagration Test Report – 522
- 'Proprietary_CEN-E5S Enclosure UL 9540A Test report – 523'
- 'Proprietary_DRAFT_Report_TR_230499RECO01_CEN_UL9540'
- 'Proprietary_E5_UL9540A Cell Report 127'
- 'Proprietary_E5S UL 9540A Module Test Report 128'
- 'Proprietary_E5S 9540A Unit Test Report – 129'
- 'Proprietary_Preliminary_Dispersion and Deflagration Modeling Progress Report'
- 'Proprietary_Vigilex_CEN-E5S_NFPA68_DesignCalcs_OD730636AV02'

The documents were reviewed in accordance with the following Codes and Standards as adopted in Santa Fe County, New Mexico:

- International Fire Code, 2021 Edition
- NFPA 855, *Standard for the Installation of Stationary Energy Storage Systems*, 2023 Edition

Where other Codes and Standards are referenced in applicable sections of the aforementioned Codes and Standards, they have been reviewed to the extent they apply.

Each review item is categorized. The categories are Code Citations and Clarifications and/or Miscellaneous Update Requests.

Based on the documents listed above, this review has concluded that a sufficient level of information has been provided to validate the issuance of a Conditional Use Permit, as it pertains to the reviewed fire and life safety codes. However, all of the items in this review letter must be satisfactorily addressed prior to commissioning of the facility.

ATAR FIRE

This detailed review has been performed by Atar Fire LLC utilizing the supplied documents, the applicable Codes and Standards, as well as engineering judgement. Atar Fire LLC assumes no liability for any errors, omissions or oversights as part of this review process. Every possible attempt has been made to thoroughly review all supplied documents and provide a review to the greatest extent possible. Our review does not constitute all possible recommendations associated with this installation, as deferred submittals and additional documentation is required prior to the commissioning of this facility, should a CUP approval be granted. Final approval of the proposed project must be issued by the County of Santa Fe, New Mexico.

Sincerely,

Nicholas Bartlett, P.E.
Professional Engineer
New Mexico License 28733
Expiration 12/31/2025

Nicholas Bartlett

Digitally signed by Nicholas Bartlett
DN: C=US, E=nick@atarfire.com, O=Atar Fire, CN=Nicholas Bartlett
Date: 2024.10.09 20:53:49-06'00'

Todd LaBerge, P.E.
Professional Engineer
New Mexico License 29658
Expiration 12/ 31/ 2024

TODD LaBERGE
NEW MEXICO
29658
PROFESSIONAL ENGINEER

Todd LaBerge

Digitally signed by Todd LaBerge
DN: C=US, E=todd@tlbfpe.com, O="TLB Fire Protection Engineering, Inc.", CN=Todd LaBerge
Reason: I have reviewed this document
Date: 2024.10.09 19:36:22-07'00'

Comment No.	Document	Page/Drawing	Comment	Code Citation, Clarification or Misc. Update Request	Open/Closed
1	Deflagration Testing	N/A	It is unclear if the provided NFPA 68 deflagration vent design from Vigilex (including the required vent area) is correlated with the deflagration testing performed by CSA. Cannot confirm if the CSA testing substantiated the installed vent size, or the opposite. Provide a rationale affirming if the CSA testing validates that the provided area, calculated prescriptively per NFPA 68, with discussion of how this relates back to the UL 9540A cell level test data, is adequate. Alternatively, with the understanding that an NFPA 69 combustible concentration reduction system will be provided, provide updated NFPA 68 calculation at the partial volume, demonstrating the provided design exceeds the required partial volume area.	NFPA 855, Section 4.2.1.3 (3)	Open
2	UL9540	N/A	A draft copy of the UL 9540 listing report has been reviewed. Certification is not complete. Completion of this project is contingent upon successful UL 9540 certification/listing.	NFPA 855, Sections 4.2.1.1 (4), 4.6.1, & 9.1.5.2.1	Open
3	N/A	N/A	The submittal did not include product cutsheets, including but not limited to: 1) BESS Product Cutsheets 2) Gas Detectors (CO and LEL Detectors) 3) Fire Alarm Components (FACP, smoke detectors, pull stations, horn/strobes, etc.) Please provide product cutsheets.	NFPA 855, Section 4.2.1.1 (7)	Open
4	N/A	N/A	A commissioning plan has not been submitted. Submit commissioning plan for review.	NFPA 855, Sections 4.2.4 & 6.1.3	Open

5	N/A	N/A	There are no shop drawings for the fire alarm system to verify NFPA 72 compliance. Provide container level drawings as well as a site diagram showing the interconnected panels. Drawings shall include items such as: One line diagram Battery Backup Calculations for fire alarm and gas detection Wire Type/Size Sequence of Operations Detector locations Lighting protection between containers; cabling means and methods between containers Circuit class And other items required by NFPA 72	NFPA 855, Section 4.2.1.1 (7); NFPA 72 Chapter 7; IFC Section 907.1.2	Open
6	N/A	N/A	There are no shop drawings for the gas detection system. Provide shop drawings for the gas detection system, if not otherwise included in the fire alarm drawings.	NFPA 855, Section 4.2.1.1 (7); NFPA 72 Chapter 7; IFC Section 907.1.2; IFC 916.2.1	Open
7	Drawings	N/A	There is no information or drawing on project signage, located on the container, near the container, and at the perimeter. Include a sheet detailing the content of the signs, and the locations, per NFPA 855 and NFPA 70. Also include signage that will be posted at the ROCC.	NFPA 855, 4.2.1.1 (6) & 4.7.4; NFPA 70 Article 706.15 (B) and (C); NFPA 855 4.7.10.	Open
8	HMA and Drawings	-	The drawings and HMA reference ‘fire separation’ within the container; however, details are not provided. Provide more detailed information on the construction of this fire separation.	NFPA 855, 4.2.1.1 (2)	Open

9	HMA	-	Fire separation within each container is credited in the HMA as a mitigating measure. Please provide the design basis. Is there a design fire and anticipated duration? Have hand calculations or a computer model been completed which demonstrate the barrier's effectiveness in preventing fire spread for a specific design fire?	Clarification Request	Open
10	N/A	N/A	Provide information on charge controllers, if provided, to confirm compliance with NFPA 855.	NFPA 855, Section 4.6.8	Open
11	N/A	N/A	Provide information on inverters and converters, if provided, to confirm compliance with NFPA 855.	NFPA 855, Section 4.6.9	Open
12	Drawings	N/A	Confirm if there are any site egress doors, if these doors have panic hardware, and if there is any associated emergency lighting.	NFPA 855, Section 4.7.8	Open
13	Drawings	N/A	Confirm the location of the disconnects to confirm NFPA 855 and NFPA 70 compliance. Ensure there is a remotely accessible disconnect. Coordinate disconnect locations with pre-incident plan and ERP.	NFPA 855 Section 5.2 and G.7.6.2; NFPA 70 Article 706.15;	Open
14	HMA and Drawings	ES-C-.02.01	The actual kWh rating of each container is unclear. The HMA says 192 MWh (Table 3, Page 3). However, it also says 8.068 MWh per enclosure which is 258 MWh (Section 3.0). Lastly, Sheet ES-C.02.01 states 277.8 MWh Provide the nameplate rating for each container and ensure all documentation (HMA, drawings, etc.) reflects this.	Clarification and Misc. Update Request	Open
15	HMA		The HMA bow tie analysis, starting with Section 5.1, relies heavily on the EPRI HMA Titled 'ESIC Energy Storage Reference Fire Hazard Mitigation Analysis' Dated December 2021. In some	Clarification and Misc. Update Request	Open

			instances, the same threats, consequences, and summary tables are used but reordered or slightly rephrased. In other instances, italics are used (see Page C-4 Table 1) which appear to be from the EPRI HMA. There is no citation provided for the EPRI document. To avoid copyright issues, please reference the EPRI document. Some language is also taken from NFPA 855, Annex G.4. (see Section 5.2.1 of HMA 'defined as a single cell failure which begins to propagate through the system' which is from NFPA 855 G.4.1). Suggest also referencing NFPA 855 where language is used directly.		
16	HMA	Section 5.2.1	Whereas the EPRI HMA utilizes a top event of a single cell failure or thermal runaway (ref EPRI HMA pages 2-2 and 3-2), and NFPA 855 Annex G.4.1 states a 'single cell failure which begins to propagate', this review recommends use of single cell failure as the top event. A single cell failure will more often than not result in either off gassing, fire, explosion, or propagation, so we want to avoid single cell failure. Please use of a single cell failure as the top event.	Clarification and Misc. Update Request	Open
17	Drawings	PV-G.01.01	Update NFPA 70 to the correct Edition. It currently shows 2017 Edition. The 2023 NFPA 855 references the 2023 NFPA 70. Note the 2021 IFC references the 2020 NFPA 70.	Misc. Update Request	Open
18	Drawings	PV-G.01.01	Add the 2021 IFC as an applicable code and standard	Misc. Update Request	Open
19	Drawings	PV-G.01.01	Break out 'NFPA' into the actual codes and editions that apply (NFPA 855 – 2023, NFPA 72, NFPA 68, NFPA 22 etc).	Misc. Update Request	Open

20	Drawings	PV-C-09.03	The fire protection water storage tank must be designed to NFPA 22. Provide a design that complies with NFPA 22.	2021 IFC 507.2.2	Open
21	Drawings	ES-C.02.01	Provide a list of acronyms in the drawing package. There are acronyms such as BOL and EOL that are not defined.	Misc. Update Request	Open
22	Emergency Response Plan	Page 5 of 20	There are knox boxes on the gates (shown on Drawings PV-E.04.01), but the response plan indicates to wait outside the gate. Provide direct guidance for where first responders should go and when/how to use the knox box.	Clarification and Misc Update Request	Open
23	Emergency Response Plan		Indicate the hours that the building on site is staffed in the response plan. In the CUP application, it says 7AM-7PM. Please confirm.	Clarification and Misc Update Request	Open
24	HMA	N/A	The deflagration vents appear to be rooftop mounted. How will they remain clear in the event of snow loads?	NFPA 68, Section 6.5.2.3	Open
25	HMA, Drawings, ERP	-	The HMA and the Drawings do not appear to show the location of the site FACP. Please indicate the location of the FACP and the strategy behind the location.	NFPA 855, Section 4.7.10 & 4.3.2.1.2	Open
26	HMA and Drawings	-	Provide details on the separation of the support enclosure (containing fire panel, etc) from the battery enclosures. Is this thermally isolated? Is this a fire barrier?	Clarification and Misc Update Request	Open
27	Drawings	-	Provide details on bracing of battery containers per local building code.	NFPA 855, Sections 4.7.2 and 4.7.3	Open
28	HMA	Page iv	Under section 'Installed per Code' delete the word 'maintained'. Maintenance is covered in the previous paragraph.	Misc Update Request	Open
29	HMA	Page 1	The NFPA 68 reference shows the 2013 Edition. NFPA 855 (2023) reference the 2018 NFPA 68. Update accordingly.	Misc Update Request	Open

30	HMA	Page 1	The NFPA 72 reference shows the 2019 Edition. NFPA 855 (2023) reference the 2022 NFPA 72. Update accordingly or seek approval to use an older edition.	Misc Update Request	Open
31	HMA	Page 1	The NFPA 2001 reference shows the 2018 Edition. NFPA 855 (2023) reference the 2022 NFPA 2001. Update accordingly or seek approval to use an older edition.	Misc Update Request	Open
32	HMA	Page 2	Table 1 and Table 2. Please include all of the failure modes and acceptance criteria, and where not applicable, state this, to provide a complete picture. For example, in Table 2, IFC 1207.1.4.2#3.	Misc Update Request	Open
33	HMA	Page 4	Figure 4. Sides A & B are referenced in the text (Section 3.1), but not in the image. Update document graphically show Sides A & B.	Misc Update Request	Open
34	Drawings/HMA	N/A	It is unclear if the coolant system is designed in accordance with the International Plumbing Code. Update HMA/Drawings with the required design information, including applicable code of record.	NFPA 855, Section 5.3.7	Open
35	N/A	N/A	Confirm that the gas sensors are compatible with the FACP	IFC 916.10	Open
36	Drawings/HMA	HMA Page 6 Section 3.2.5	Provide separate horn/strobes, with different colors, for gas detection and fire alarm. 2021 IFC: "Audible and visible alarms associated with a gas detection alarm shall be distinct from fire alarm and carbon monoxide alarm signals". Label the strobes indicating the function. For example, 'GAS DETECTION' and 'FIRE ALARM'.	IFC 916.8; NFPA 72 Section 10.10	Open
37	HMA	HMA Page 6 Section 3.2.5	Define 'low' gas level. Please provide the alarm levels for LEL and CO detectors (in % LFL or ppm).	Misc Update Request	Open

38	Drawings	N/A	Provide location for notification appliances. Coordinate location with ERP to ensure first responder visibility.	Misc Update Request	Open
39	HMA	Page 13 Section 3.2.6	This section utilizes the title 'fire suppression'. A fire suppression system needs to comply with NFPA 855, 4.9.3, including testing per 9.1.5. Provide documentation demonstrating this system complies with applicable requirements for a fire suppression system.	NFPA 855 4.9.3, and 9.1.5. Misc Update Request	Open
40	HMA	Page 13 Section 3.2.6	Please clarify the intent and application of NFPA 855 to this system. It cannot be determined if the system is for suppression or for thermal runaway propagation prevention. If this is not a fire suppression system, specifically invoke AHJ approval for omission of fire suppression system per NFPA 855 Section 9.5.2.5		
41	HMA	Section 3.2.6	If the NOVEC 1230 system is a thermal runaway propagation prevention system, provide a separate report interpreting the test results, defining the applicable codes and standards, and validating the use and limitations.	NFPA 855, 9.1.5.2.2	Open
42	HMA or Drawings	N/A	Confirm that each FACP will have a unique identifier, and that each container will be labeled accordingly. For example, if an alarm signal states 'CONTAINER 19', then the number '19' should be on each container in large letters viewable at 100 feet from the anticipated side that the fire department will approach	2021 IBC 502.1; 2021 IFC 907.6.3; NFPA 855 G.1.4.2.1.1, G1.4.2.1.2	Open
43	HMA	Section 5.2.1 & Page 11	All of the items in Table 5 appear to be threats except the first two. 'Single Cell Thermal Runaway' and 'Multi Cell Thermal Runaway'. These are Consequences and/or Top Events. Also	Misc Update Request	Open

			refer to sample EPRI HMA (Table 2-2 & 3-2). Update HMA accordingly.		
44	HMA	Page 12	The Direct Injection System is credited as a preventative barrier. This system requires a fire or cell failure (utilizing smoke detection) to operate. Please determine if this is a mitigative or preventative barrier, based on if BMS signals are also utilized to trigger it. Revise or confirm as appropriate.	Misc Update Request	Open
45	HMA	Page 13	Table 7. Combine 'Cell Off-Gassing/Explosions' and 'Accumulation of Off Gasses/ Delayed Explosions'. Accumulation will always occur even with a single cell that off gasses, where an NFPA 68 system is used. In addition, more cells do not always create a worse explosion. More cells can lead to a less than stoichiometric condition inside the container. A single cell can lead to a partial volume deflagration.	Misc Update Request	Open
46	HMA	Page 14	Thermal Isolation for both the 'Enclosure Insulation' and 'Module/Rack Separation' is credited. However, details are not provided on these, so it is unclear how/why these are being credited as a mitigative barrier. Please provide more descriptive detail on whey these are credited as a mitigating barrier and any date to support the analysis.	Clarification and Misc Update Request	Open
47	HMA	Page 15	The diagrams are difficult to review. Please provide more clear diagrams.	Misc Update Request	Open
48		Page 15	Figure 6/7/8. Under the line 'Cell Off Gassing/Explosions', deflagration venting is missing as a mitigating measure.	Misc Update Request	Open
49	HMA	Page 16/17	The terms 'depending upon final site installation/conditions' is repeated. The HMA	Misc Update Request	Open

			must reflect this specific installation and dictate all required parameters. Please revised and clarify.		
50	HMA	Page 16	The statement 'in effect acts to increase the effectiveness of the smoke and gas detection systems by providing an increased amount of time for event detection prior to the development of untenable conditions.' is not accurate, as it pertains to the direct injection system. The direct injection system activates on smoke according to the HMA. It will do nothing to increase the amount of time for event detection. Please update.	Misc Update Request	Open
51	HMA	Page 17, Section 5.3.2	The sentence 'The effectiveness of the system/disconnect capability may be subject to site conditions.' must be defined for this specific site. Please update to specifically address site installation.	Clarification Request	Open
52	HMA	Page 17, Section 5.3.3	The sentence 'Failure of any of the above listed system' is incorrect without further documentation. This review could not confirm the Listings on the direct injection system, the gas sensors, the deflagration panels, or the fire alarm system. Provide Listing information to validate the statement.	Misc Update Request	Open
53	HMA	Page 18	The statement that the 'strength of gas detection system and direct injection is conditional based on the quality and use of the emergency response plan' is a very loose association. Please clarify how these systems are conditional based on the quality and use of the ERP, or remove.	Misc Update Request	Open

54	HMA	Page 18, Section 5.3.5	The word 'can' is used in the sentence 'insulation monitoring can also serve…'. Please detail whether there is insulation monitoring or not, and the purpose/benefit.	Clarification & Misc Update Request	Open
55	ERP		Confirm the planned location of the ERP. Indicate this location in the ERP.	NFPA 855 4.3.2.1.2	Open
56	ERP	Section 4.1	The second paragraph in Section 4.1 is duplicated. It is the same as the second sentence of the first paragraph.	Misc Update Request	Open
57	ERP	Page 5 of 20	Move Page 5 of 20 to Page 2. After the cover page, this is the most important page and will be used as a quick reference for responders. They should not be searching through a table of contents, revision log, etc, to find this.	Misc Update Request	Open
58	ERP	Page 5 of 20	Put the contact number of AES responders/personnel right up front. For example: "REMAIN OUTSIDE THE FRONT GATE UNTIL ENTRY IS GRANTED BY AES PERSONNEL. IF AES PERSONNEL ARE NOT PRESENT, CALL	Misc Update Request	Open

			EMERGENCY LINE AT XXX-XXX-XXXX TO BEGIN COORDINATION’		
59	ERP	Page 5 of 20	Following the content in comment 61 above, add sentence stating something like ‘DO NOT OPEN CONTAINER DOORS – EXPLOSION HAZARD MAY OCCUR’. It is imperative this message is conveyed clearly.	Misc Update Request	Open
60	ERP	Page 5 of 20	Item 4. Change to ‘First responders must wear PPE’ on scene. It is not an option and needs to be explicit.	Misc Update Request	Open
61	ERP, HMA	N/A	It is understood that the gas sensor signals will go to the AES 24/7 monitoring service (and will not be transmitted via the fire alarm system). Please confirm this, the intended response by various parties, and clarify in the ERP and HMA.	NFPA 855, 4.3.2.1.4 (3)	Open
62	ERP	N/A	Once comments 36/38 are addressed, ensure the final ERP has photos of the gas sensor and the fire alarm strobe for visual representation.	Misc Update Request	Open

63	ERP	Page 9 of 20	The sentence 'The BESS containers are adequately separated by approximately 22 feet…' is not consistent with the project documents, which notes the containers are 3.5 feet apart.	Misc Update Request	Open
64	HMA and ERP	Page 9 of 20	The ERP references FM 5-33 (See Page 9 of 20). However, the HMA and design documents not appear to be written or intended to comply with FM 5-33. Is the installation intended to comply with FM 5-33? Please confirm. The use of FMDS 5-33 requires approval as an Alternative Means and Methods per IFC Section 104.	Clarification Request	Open
65	ERP	Section 4.1.1	The last paragraph of Section 4.1.1 refers to NOVEC suppression for the container. Confirm if container based NOVEC is being provided or if it is direct injection thermal runaway propagation prevention system. The ERP and HMA contain conflicting information.	Misc Update Request	Open
66	ERP	Section 5.1	Change the word 'should' in the following sentence to 'must' or 'shall': 'Due to the various gases present (listed above) appropriate PPE, including SCBA, should be worn.'	Misc Update Request	Open

67	ERP	Section 5.3	This section notes that the deflagration panels will release to the sides. It is our understanding the deflagration panels are roof mounted, as described in the HMA. Please clarify and coordinate.	Misc Update Request	Open
68	ERP	Page 13 of 20	There is an incomplete sentence: 'Upon notification of an incident at, '. Please correct/resolve.	Misc Update Request	Open
69	ERP	Page 13 of 20	The status of the gas detection system must also be considered in the following section: 'Has the Suppression System or Fire Detection System activated'. Revise to include gas detection.	Misc Update Request	Open
70	ERP	Page 14 of 20	The language of 'Initial Entry' must clearly detail the container doors are not to be opened by first responders.	Misc Update Request	Open
71	ERP	Page 14 of 20	Clarify the intent regarding the NOVEC system in the section titled 'BESS Fire Protection System'. See other comments on this topic such as Comment 65. Coordinate any changes.	Misc Update Request	Open

72	ERP	Page 15 of 20	Road labels are illegible on the current map. Revise to more clearly label the roads for ease of identification.	Misc Update Request	Open
73	ERP	Page 16 of 20	Figure 2 does not clearly and legibly identify the site infrastructure and details. Revise the map to more completely detail the facility layout, such as transformers, water tanks, roads, PV arrays, etc.	Misc Update Request	Open
74	ERP	Page 18 of 20	The schematic shows two horn strobes. Other references to notification device(s) in the HMA indicate there is only one. Please clarify and coordinate. See also comment 36/38 related to providing separate gas detection/fire alarm horn strobes. Spell out acronyms HFR and LFR.	Clarification & Misc Update Request	Open
75	ERP	Page 12 of 20	Site familiarization and tours must include other potential responders, which could include Federal Agencies (EPA), County Haz Mat, Environmental, and Emergency Management, and others that could conceivably respond to an incident. Section 6.1 only refers to the Fire Department.	Misc Update Request	Open

76	ERP	General	The ERP does not mention the water tank. Include information regarding the location, size, and purpose of the water tank in the ERP.	Misc Update Request	Open
77	ERP	Page 7 of 20	In Table 2, it states 'Deflagration Wall Panels'. Based on the HMA (see Section 3.2.2 of HMA), these are rooftop panels. Please update/coordinate.	Clarification & Misc Update Request	Open
78	ERP	General	The ERP must clearly define the meeting/convergence point, if present.	Clarification & Misc Update Request	Open
79	Pre-Plan	N/A	Provide language clarifying 'CENS' as this is not common language for first responders	Misc Update Request	Open
80	Pre-Plan	N/A	Same comment as 41/65/71 regarding the 'Novec Suppression', but for the pre incident plan. Additional information is required about the NOVEC system. Clearly define the suppression system and associated hazards in the ERP.	Clarification & Misc Update Request	Open

81	Pre-Plan	N/A	Provide annotations on the map for PV arrays, BESS containers, Operations Building, Water Supply, and access road.	Clarification & Misc Update Request	Open
82	Pre-Plan	N/A	Under 'Special Conditions and Hazards' after **Lithium Ion Batteries & High Voltage** include a line stating in capital letters 'EXPLOSION HAZARD' or 'EXPLOSION HAZARD – DO NOT OPEN DOORS'.	Misc Update Request	Open
83	N/A	N/A	Provide a maintenance plan, including tasks and requisite intervals, for BESS maintenance functions, NFPA 68, NFPA 72, and direct injection maintenance items.	NFPA 855, 7.1.2 and G.10.2.1	Open
84	HMA	N/A	Confirm how and if BMS alarms are being monitored 24/7. Current industry practice is moving toward ensuring this data is monitored by a Network Operations Center. Refer to New York State Interagency Fire Safety Work Group Fire Code Recommendations July 2024	Clarification Request	Open
85	Drawings	N/A	Place large signage on containers stating "EXPLOSION HAZARD WHEN IN ALARM. STAND BACK". Signage to be viewable from 100 feet away. Provide signage that is legible at night	NFPA 855 G.1.4.2.1.1	Open

86	Drawings/HMA	N/A	Provide a visual annunciation/beacon at the entry to the BESS area to indicate potentially hazardous conditions that could exist, including BMS, Gas, and Smoke alarms.	NFPA 855, 9.2.3.3	Open
87	N/A	N/A	Confirm AES capabilities for air monitoring during a large-scale incident to inform need for public protective measures.	Clarification Request	Open
88	Draft UL 9540 Report	N/A	Section 19.2 indicates N/A for ASME B31 (or equivalent) for piping carrying fluids. Confirm what piping standards the coolant and the NOVEC are constructed to, or have SGS explain why this is an 'N/A'.	Clarification Request	Open
89	Draft UL 9540 Report		Provide a copy of the following documents for review: 1) FMEA for UL 9540 2) UL 60730-1 Evaluation	Clarification Request	Open
90	Drawings		Provide shop drawings for the NOVEC system for review.	NFPA 855, 4.2.1.1 (7)	Open

91	N/A		Provide complete NFPA 69 compliant combustible concentration reduction system, including all necessary support documentation.		Open
92	N/A		The CSA deflagration report concludes the internal divider wall collapsed during testing (page 13 of 22). NFPA 68 (2023) Section 7.2.5.11 requires interior partitions that cannot withstand the expected pressure not be considered part of the calculations. Please provide an interpretation, in the light of the CSA testing results that indicate interior partition collapse, the Vigilex Calculations based on an approximately 20 ft container length, and this NFPA 68 requirement, if the vent panel design is still appropriate.	NFPA 68, 7.2.5.11	Open
93	HMA		The HMA should discuss that the NOVEC system, which has been tested as part of UL 9540A Unit and Installation Level tests, is required for compliance with NFPA 855, Section 9.1.5.1.2, and via UL 9540A Section 9.1.7. This system is being used to demonstrate that fire in one unit will not propagate to another unit. Without this system, the UL 9540A unit/installation testing is no longer valid (per UL 9540A Section 9.1.7 and NFPA 855, 9.1.5.1.2 and 9.1.5.1.3) and a large-scale fire test would be necessary. The HMA should clarify this so the purpose, limitations, and application of code are understood. In addition, because this system is not an NFPA 2001 system per NFPA 855 4.9.3.2, it cannot be	Clarification Request	Open

			called a fire suppression system (see other comments related to this).		

Exhibit 3

UNIT TEST REPORT
UL 9540A
Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems (AACD)

Project Number..............................:	**4790294261**
Date of issue ....:	**2022-09-05**
Total number of pages...................:	**41**
UL Report Office ....:	**UL(Changzhou) Quality Technical Service Co., LTD**
Applicant's name...........................:	**Contemporary Amperex Technology Co Limited**
Address ....:	**No.2 Xingang Road Zhangwan Town, Jiaocheng District, Ningde, FuJian 352100 China**
Test specification:	4th Edition, Section 9, November 12, 2019
Standard ....:	UL 9540A, Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems
Test procedure ....:	9.1 – 9.8
Non-standard test method ....:	N/A

General disclaimer:

The test results presented in this report relate only to the sample tested in the test configuration noted on the list of the attachments.

UL LLC did not select the sample(s), determine whether the sample(s) was representative of production samples, witness the production of the test sample(s), nor were we provided with information relative to the formulation or identification of component materials used in the test sample(s).

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Cell level information	
Cells in Module:	
•Manufacturer Name	Contemporary Amperex Technology Co Limited
•Part Number	CB310, CB2W0
•Chemistry	Lithium iron phosphate
•Format	Prismatic
Ratings (Vdc, Ah) :	3.2V, 280Ah
Cell certified? :	Yes
Standard the cell was certified to:	UL1973
Organization that certified the cell:	UL (MH62898)
Average cell surface temperature at gas venting, ℃:	168.2
Average cell surface temperature at thermal runaway, ℃:	239.6
Gas Volume:	221.3L
Lower flammability limit (LFL), % volume in air at the ambient temperature:	7.85
Lower flammability limits (LFL), % volume in air at the venting temperature:	6.47
Burning velocity (S_u) cm/s:	64
Maximum pressure (P_{max}) psig:	103

Cell level Gas Composition:

Gas		Measured %
Carbon Monoxide	**CO**	11.086
Carbon Dioxide	**CO_2**	33.290
Hydrogen	**H_2**	35.698
Methane	**CH_4**	10.075
Acetylene	**C_2H_2**	0.164
Ethylene	**C_2H_4**	5.259
Ethane	**C_2H_6**	1.089
Propadiene (Allene)	**C_3H_4**	0.000
Propyne	**C_3H_4**	0.000
Propene	**C_3H_6**	0.571
Propane	**C_3H_8**	0.232
-	**C4 (Total)**	0.382
-	**C5 (Total)**	0.091
-	**C6 (Total)**	0.060
-	**C7 (Total)**	0.005
-	**C8 (Total)**	0.000
Benzene	**C_6H_6**	0.023
Toluene	**C_7H_8**	0.002

Dimethyl Carbonate	**$C_3H_6O_3$**	1.879
Ethyl Methyl Carbonate	**$C_4H_8O_3$**	0.091
Diethyl Carbonate	**$C_5H_{10}O_3$**	0.000
Total	**-**	**100**

Module level Information

Model No... :	M52280-E, M52280-P
Ratings (Vdc, Ah)............................. :	166.4V 280Ah
Module dimensions (X x **Y** x **Z** (mm))..................:	810±5mm*1155±5mm*243.4±5mm
Module cell configuration (xS/yP) ......:	52S/1P
Module weight (kgs)............................ :	330±5kg
Module enclosure material.................... :	Top enclosure is made of plastic bottom enclosure is made of aluminium alloy
Was the module certified? ....:	No
Standard the module was certified to ....:	N/A
Organization that certified test item ....:	N/A
Number of initiating cells failed to achieve propagation.	1
Thermal Runaway Propagation:	Initiating cell went into thermal runaway and propagated to two adjacent cells
External Flaming:	No external flaming occurred.
Location(s) of Flame Venting:	No flaming occurred
Flying Debris:	No flying debris observed.
Re-ignitions:	No further re-ignitions were observed during post test observation.
Test Maximum Smoke Release Rate (m^2/s)	4.9
Test Total Smoke Released: (m^2)	376.7
Test Peak Chemical Heat Release Rate: (kW):	No flaming observed

Module level test Gas Composition & Volume for Each Compound (Pre-flaming and After flame):

Gas Compound	Gas Type	Pre-Flaming (L)	Flaming (L)	Minimum detectable flow rate (LPM)
Total Hydrocarbons (Propane Equivalent)	Hydrocarbons	150	No flaming	0.52
Carbon Monoxide	Carbon Containing	53	No flaming	0.68
Carbon Dioxide	Carbon Containing	143	No flaming	2.98
Hydrogen	Hydrogen	189	No flaming	8.79

Unit level Information	
Model No.:	Ox52280-E, Ox52280-P
Ratings (Vdc, Ah) ....:	1331.2Vdc, 280Ah
BESS dimensions (W x **D** x **H** (mm))..................:	1300(W)x1300(D)x2280(H)
BESS module configuration	8S/1P
Number of modules in BESS	8
Module cell configuration (xS/yP) ......:	52S/1P
Number of cells in module.:	52
BESS weight (kgs)........................... :	3650
BESS enclosure material.................... :	Galvanized steel
BESS Intended Installation: **Non Residential:** outdoor ground mounted, indoor floor mounted, outdoor wall mounted, indoor wall mounted, roof top, open garage **Residential:** Outdoor ground mounted, indoor floor mounted, outdoor wall mounted, indoor wall mounted	Non Residential: outdoor ground mounted, indoor floor mounted
Residential Indoor Use: Smallest volume room installations specified.	N/A
Original Equipment Manufacturer (OEM):	Contemporary Amperex Technology Co., Limited
Branding Manufacturer (if not OEM):	N/A
Was the unit certified? ....:	Yes
Standard the unit was certified to ....:	UL 1973
Organization that certified the unit ....:	TUV SUD (No.U14 004951 0008 Rev.00/No.U14 004951 0008 Rev.01)
Cell failure test method performed (summary of method and test clause): ☒ External heating using thin film with 4 ℃ to 7 ℃ thermal ramp. ☐ Nail Penetration ☐ Overcharge ☐ External short circuit (***X*** Ω *external resistance*) ☐ Others	
Description of method used to fail cells if other than external thin film heater with thermal ramp, : N/A	
Description of components employed within the BESS unit that serve to suppress propagation (fire protection features) Liquid coolant and aerosol system were employed in the container; however, the pipes for the coolant were empty without the coolant and both coolant system and the aerosol system were not powered during the test at the request of the applicant (CONTEMPORARY AMPEREX TECHNOLOGY CO., LIMITED) Therefore, these systems were neither used nor evaluated in the test; the detailed information on these systems are described in the critical components.	
Deviation from the module level test	

N/A	
Number of initiating cell(s)	1
Thermal Runaway Propagation:	Initiating cell went into thermal runaway and propagated to one adjacent cell.
External Flaming from BESS:	No external flaming occurred
Location(s) of Flame Venting:	No Flaming occurred
Maximum Target BESS Temperature, ℃	30
Maximum Wall Surface Temperature[1], ℃	29
Peak Chemical Heat Release Rate, kW	No flaming observed
Peak Convective Heat Release Rate, kW	No flaming observed
Maximum Smoke Heat Release Rate, m^2/s	0.23
Maximum Heat Flux on Target Modules, kW/m^2	0
Maximum Heat Flux of Egress Path, kW/m^2	0
Flying Debris:	No flying debris observed
Re-ignitions:	No further re-ignitions were observed during post test observation

Gas Analysis:

☒ Flame ionization detection (FID)

☒ Non-Dispersive Infrared Spectrometer (NDIR)

☐ Fourier-Transform infrared Spectrometer

☒ Hydrogen Sensor (palladium-nickel, thin-film solid state sensor)

☒ White light source with photo detector (smoke release rate)

Summary of Unit level test Gas Analysis Data:

Unit level Gas Composition & Volume for Each Compound (Pre-flaming and After flame):

Gas Compound	Gas Type	Pre-Flaming (L)	Flaming (L)	Minimum detectable flow rate (LPM)
Total Hydrocarbons (Propane Equivalent)	Hydrocarbons	284	No flaming	0.65
Carbon Monoxide	Carbon Containing	0.23	No flaming	0.26
Carbon Dioxide	Carbon Containing	7.51	No flaming	0.85
Hydrogen	Hydrogen	121.8	No flaming	6.44

Summary of BESS Unit Test Results

Performance Criteria in accordance with Table 9.1 for Indoor Floor Mounted non-residential unit

[1] Maximum wall surface temperature averaged on 60 seconds.

[X] Flaming outside the initiating BESS unit was not observed; **[X]** Surface temperatures of modules within the target BESS units adjacent to the initiating BESS unit did not exceed the temperature at which thermally initiated cell venting occurs, as determined in 7.3.1.8; **[X]** For BESS units intended for installation in locations with combustible constructions, surface temperature measurements on wall surfaces did not exceed 97 ℃ (175 ℉) of temperature rise above ambient per 9.2.15; **[X]** Explosion hazards were not observed, including deflagration, detonation or accumulation (to within the flammability limits in an amount that can cause a deflagration) of battery vent gases; and **[X]** Heat flux in the center of the accessible means of egress did not exceed 1.3 kW/m^2.		
Performance Criteria in accordance with Table 9.1 for Outdoor Ground Mounted non-residential unit **[X]** Separation distances to exposures was farther than the greatest flame extension observed during test. **[X]** Surface temperatures of modules within the target BESS units adjacent to the initiating BESS unit did not exceed the temperature at which thermally initiated cell venting occurs, as determined in 7.3.1.8; **[X]** For BESS units intended for installation in locations with combustible constructions, surface temperature measurements on wall surfaces did not exceed 97 ℃ (175 ℉) of temperature rise above ambient per 9.2.15; **[X]** Explosion hazards were not observed, including deflagration, detonation or accumulation (to within the flammability limits in an amount that can cause a deflagration) of battery vent gases; and **[X]** Heat flux in the center of the accessible means of egress did not exceed 1.3 kW/m^2.		
Necessity for an Installation level test		
[ ] The performance criteria of the unit level test as indicated in Table 9.1 of UL 9540A 4th edition has not been met, therefore an installation level testing in accordance with UL 9540A will need to be conducted on the representative the installation with this unit installed. **[X]** The performance criteria of the unit level tests as indicated in Table 9.1 of UL 9540A 4th edition has been met, therefore an installation level testing in accordance with UL 9540A need not be conducted.		
Testing Laboratory Information		
Testing Laboratory and testing location(s):		
Testing Laboratory:	Beijing Building Materials Testing Academy	
Testing location/ address .... :	#17 Raxin Road, Doudian Town, Fangshan district, Beijing 102402, CN	
Tested by (name, signature) .... :	[redacted]	
Witnessed by (for 3rd Party Lab Test Location) (name, signature) .... :	[redacted]	[redacted]
Project Handler (name, signature).............. :	[redacted]	[redacted]
Reviewer (name, signature) ……………..:	[redacted]	[redacted]

List of Attachments (including a total number of pages in each attachment):
Attachment A: Sample Charging, OCV and SOC Measurement Profiles - (*Pages **28** through**28***)
Attachment B: BESS (including module and any integral fire detection and suppression systems) Construction Photos/Diagrams - (*Pages **29** through **29***)
Attachment C: BESS and Equipment Instrumentation and Test Installation Layout Photos/Diagrams - (*Pages **30** through **31***)
Attachment D: Temperature Profiles and Heat Flux Measurements During Testing (Initiating Cell and Module, Target Modules, Wall Surfaces, etc. - (*Pages **32** through **35***)
Attachment E: BESS Unit Testing and Post Testing Photos - (*Pages **36** through **38***)
Attachment F: BESS Unit Gas Flow Rate and Heat Release and Smoke Release Profiles – (*Pages **39** through **41***)

Photo(s) of BESS unit:

Test Item Charge/Discharge Specifications:	Ox52280-E[2]	Ox52280-P
• Charge power, W:	186.4kW	372.7kW
• Standard Full charge voltage, Vdc:	1497.6V or single cell reach 3.6V	1497.6V or single cell reach 3.6V
• Charge temperature range, ℃:	0~55	0~55
• End of charge current, A:	N/A	N/A
• Discharge power, W:	186.4kW	372.7kW
• End of discharge voltage, Vdc:	1164.8V or single cell reach 2.8V	1164.8V or single cell reach 2.8V
• Discharge temperature range, ℃:	0~55	0~55

[2] Ox52280-E was use for this test.

Test item particulars ....:	
Possible test case verdicts:	
- test case does not apply to the test object...........:	N/A
- test object does meet the requirement ....:	P (Pass)
- test object does not meet the requirement...........:	F (Fail)
- test object was completed per the requirement...:	C(Complete)
- test object was completed with modification……:	M(Modification)
Testing..:	
Date of receipt of test item ....:	2022.06.27
Date (s) of performance of tests ....:	2022.07.04
General remarks:	
"(See Enclosure #)" refers to additional information appended to the report. "(See appended table)" refers to a table appended to the report. **Throughout this report a point is used as the decimal separator.**	
Manufacturer's Declaration of samples submitted for test:	
The applicant for this report includes samples from more than one factory location and a declaration from the Manufacturer stating that the sample(s) submitted for evaluation is (are) representative of the products from each factory has been provided ....:	☒ **Yes** ☐ **Not applicable**
Name and address of factory (ies) ....:	Manufacture-1: Contemporary Amperex Technology Co Limited[3] No.2 Xingang Road Zhangwan Town, Jiaocheng District, Ningde, 352100 Ningde, Fujian, PEOPLE'S REPUBLIC OF CHINA Manufacture-2: Guangdong Ruiqing Contemporary Amperex Technology Limited No.1 Contemporary Avenue, Sihui City, Zhaoqing City, Guangdong Province, People's Republic of China Manufacture-3: Sichuan Contemporary Amperex Technology Limited No.1 Chanye Avenue, Lingang Economic Development Zone, Yibin City, Sichuan

[3] Test unit samples were produced in the factory located at No.2 Xingang Road Zhangwan Town, Jiaocheng District, Ningde, 352100 Ningde, Fujian, PEOPLE'S REPUBLIC OF CHINA (Contemporary Amperex Technology Co Limited)

General product information and other remarks:
Battery Module Model M52280-E employs cell Models CB310 manufactured by Contemporary Amperex Technology Co Limited. Battery Module Model M52280-P employs cell Model CB2W0 manufactured by Contemporary Amperex Technology Co Limited. The cell Model CB2W0 is identical to model CB310 in construction except for the declared charge and discharge current rating. The normal charge and normal discharge current rating for Model CB310 are 140A. The normal charge and normal discharge current rating for Model CB2W0 are 280A. The Battery Module Model M52280-P is identical to model M52280-E in construction except for the declared charge and discharge current rating. The unit sample tested in this project was Ox52280-P with module M52280-P. The test module is without mica sheet.

5.0	CONSTRUCTION		Verdict
5.3	**Battery energy storage system unit Construction**		—
5.3.1, 5.3.2	Construction information	See Test Item Description at the beginning of this report	—
5.3.2	General layout of BESS unit contents	See Attachment B	—
5.3.3	Details of integral fire suppression system	See Attachment B	
5.3.1	BESS certified to UL 9540	No	
	Organization that certified BESS:	N/A	—
6.0	**PERFORMANCE**		**Verdict**
6.1	**General**		
9.1	**Sample and test configuration**		
9.1.1	The unit level test conducted with BESS units installed as described in the manufacturer's instructions.	See Attachment C for test installations Installation type: outdoor ground mounted, indoor floor mounted.	C
9.1.2	The unit level test required one initiating BESS unit in which an internal fire condition in accordance with the module level test is initiated and target adjacent BESS units representative of an installation.	See Attachment C for test installations	C
	Tests conducted for indoor floor mounted installations are representative of both indoor floor mounted and outdoor ground mounted installations.		C
	Tests conducted indoors with fire propagation hazards and separation distances between initiating and target units representative of the installation.		C
	Testing conducted outdoors for outdoor only installations with following in place: a) Wind screens with wind speed of ≤ 12 mph; b) Temperature range is 10 ℃ to 40 ℃ (50 ℉ to 104 ℉); c) Humidity is < 90% RH; d) Sufficient light to observe the testing; e) There is no precipitation; f) There is control of vegetation and combustibles in the test area; and g) There are protection mechanisms in place to prevent inadvertent access by unauthorized persons in the test area.	The product is not outdoor use only type. The test was conducted indoor.	N/A

UL 9540A, Edition 4,			
Clause	Requirement + Test	Result - Remark	Verdict
9.1.3	Testing to determine fire characterization was done at the battery system level rather than a complete BESS	Complete ESS was installed inside the unit.	N/A
9.1.4	The initiating BESS contained components representative of a BESS unit in a complete installation.	The BESS included the Power Conversion System	N/A
	Combustible components that interconnect the initiating and target BESS units was included.	Wires were used to connect the units.	C
9.1.5	Target BESS units include the outer cabinet (if part of the design), racking, module enclosures, and components that retain cells components.		C
9.1.6	The initiating BESS was at the maximum operating state of charge (MOSOC),	See Table 2 and Attachment A	C
	After charging and prior to testing, the initiating BESS was at rest for a maximum period of 8 hours at room ambient.	See Table 2	C
9.1.7	The BESS unit included an integral fire suppression system.	The fire suppression system was installed for the test, however, the system was not activated at the request of Contemporary Amperex Technology Co Limited	C
9.1.8	Electronics and software controls such as the battery management system (BMS) are not relied upon for this testing.		C
	Included a fire suppression control in accordance with UL 864 that is external to the BESS.		N/A
9.2	**Test method – Indoor floor mounted BESS units**		
9.2.1	Test room ambient temperature within 10 ℃ (50 ℉) to 32 ℃ (90 ℉).	See Table 2	C
9.2.2	Access door(s) or panels on the initiating BESS unit and adjacent target BESS units were closed, latched and locked duration of the test.		C
9.2.3	The initiating BESS unit was positioned adjacent to two instrumented wall sections.	Attachment C	C
9.2.4	Instrumented wall sections extend not less than 0.49 m (1.6 ft) horizontally beyond the exterior of target BESS units.		C
9.2.5	Instrumented wall sections were at least 0.61-m (2-ft) taller than the BESS unit height, but not less than 3.66 m (12 ft) in height above the bottom surface of the unit.		C

UL 9540A, Edition 4,			
Clause	Requirement + Test	Result - Remark	Verdict
9.2.6	The surface of the instrumented wall sections were covered with 16-mm (5/8-in) gypsum wall board and painted flat black.	See Attachment C The test was to cover outdoor use as well, however, gypsum was used.	M
9.2.7	The initiating BESS unit was centered underneath an appropriately sized smoke collection hood of an oxygen consumption calorimeter.		C
9.2.8	The light transmission in the calorimeter's exhaust duct was measured using a white light source and photo detector. The smoke release rate was calculated.	See Table 12 See Attachment F	C
9.2.9	The chemical and convective heat release rates were measured for the duration of the test.	See Table 12 See Attachment F	C
9.2.10	The heat release rate measurement system was calibrated using an atomized heptane diffusion burner. The calibration was performed using flows of 3.8, 7.6, 11.4 and 15.2 L/min (1, 2, 3 and 4 gpm) of heptane.		C
9.2.11	The chemical heat release rate was measured using the following equipment: ● Paramagnetic oxygen analyser ● Non-dispersive infrared carbon dioxide and carbon monoxide analyser ● Velocity probe ● Type K thermocouple		C
9.2.12	The chemical heat release rate at each of the flows was calculated.		C
9.2.13	The physical spacing between BESS units (both initiating and target) and adjacent walls was representative of the intended installation.	See Attachment C	C
9.2.14	Separation distances were specified by the manufacturer for distance between: a) The BESS units and the instrumented wall sections; and b) Adjacent BESS units.	See Attachment C	C
9.2.15	Wall surface temperature measurements were collected	See Table 6 See Attachment D	C
	The intended installation is composed completely of non-combustible construction		C

UL 9540A, Edition 4,			
Clause	Requirement + Test	Result - Remark	Verdict
9.2.16	Wall surface temperatures were measured in vertical array(s) at 152-mm (6-in) intervals for the full height of the instrumented wall sections using No. 24-gauge or smaller, Type-K exposed junction thermocouples.		C
	The thermocouples for measuring the temperature on wall surfaces were horizontally positioned in the wall locations to receive greatest thermal exposure from the initiating BESS unit.		C
9.2.17	Thermocouples were secured to gypsum surfaces and the thermocouple tip was depressed into the gypsum so as to be flush with the gypsum surface at the point of measurement .		C
9.2.18	Heat flux was measured with at least two water-cooled Schmidt-Boelter gauges at the surface of each instrumented wall: a) Both are collinear with the vertical thermocouple array; b) One is positioned to receive the greatest heat from the initiating module; and c) One is positioned to receive the greatest heat flux during potential propagation within the initiating BESS unit.		C
9.2.19	Heat flux was measured with 2 water-cooled Schmidt-Boelter gauges at the surface of each adjacent target BESS units facing initiating BESS unit: a) One is positioned at the elevation estimated to receive the greatest heat flux from the initiating module; and b) One is positioned at the elevation estimated to receive the greatest surface heat flux due to initiating BESS.	There is only one heat flux in the target unit-1, position at the mid height of the initiating module; there are two heat fluxes for other target units.	M
9.2.20	Heat flux was measured with the sensing element of at least one water-cooled Schmidt-Boelter gauge positioned in the center of the accessible means of egress.	The distance between the unit and gauge is 0.1m. The height of the gauge is 0.85m.	C
9.2.21	No. 24-gauge or smaller, Type-K exposed junction thermocouples were installed to measure the temperature of the surface proximate to the cells and between the cells and exposed face of the initiating module.	See Attachment C	C
	Each non-initiating module enclosure within the initiating BESS unit was instrumented with at least one No. 24-gauge or smaller Type-K thermocouple(s) within non-initiating modules.	See Attachment C	C

UL 9540A, Edition 4,			
Clause	Requirement + Test	Result - Remark	Verdict

	Additional thermocouples were placed to account for convoluted geometries.		N/A
9.2.22	For residential use, the DUT was covered with a single layer of cheese cloth ignition indicator. The cheesecloth was untreated cotton cloth running 26 – 28 m2/kg with a count of 28 – 32 threads in either direction within a 6.45 cm^2 (1 in^2) area.	Non residential use.	N/A
9.2.23	An internal fire condition in accordance with the module level test was created within a single module in the initiating BESS unit: a) The position selected to present the greatest thermal exposure to adjacent modules; and b) The setup was the same as that used to initiate and propagate thermal runaway within the module level test.	See Attachment C	C
9.2.24	The composition, velocity and temperature of the initiating BESS unit vent gases was measured within the calorimeter's exhaust duct. Composition, velocity and temperature instrumentation shall be collocated with heat release rate calorimetry instrumentation.		C
	Hydrogen gas shall be measured with a palladium-nickel thin-film solid state sensor.		C
	The hydrocarbon content of the vent gas may also be measured using a Fourier-Transform Infrared Spectrometer with a minimum resolution of 1 cm-1 and a path length of at least 2 m (6.6 ft), or equivalent gas analyzer.	FTIR analysis was not used in accordance with the Certification Requirement Decision: Corrections to gas measurement methods to make FTIR as an option for measuring hydrocarbon contents of gas emissions and to include Hydrogen measurements during the Unit Level Test.	N/A
9.2.25	The hydrocarbon content of the vent gas was measured using flame ionization detection.	See Tables 8, 9, 10 and 11	
9.3	**Test method – Outdoor ground mounted units**		
9.3.1	Outdoor ground mounted non-residential use BESS for installation: test method described in Section 9.2 was used.		C

UL 9540A, Edition 4,			
Clause	Requirement + Test	Result - Remark	Verdict

	Outdoor use only installations: the smoke release rate, the convective and chemical heat release rate and content, velocity and temperature of the released vent gases were not be measured.	The parameters were measured for indoor use evaluation.	N/A
9.3.2	Outdoor ground mounted residential use BESS: The test method described in Section 9.2 except as noted in 9.3.3 and 9.3.4.	These parameters were measured for indoor use evaluation.	N/A
	Heat flux measurements for the accessible means of egress were measured in accordance with 9.2.20.		C
	Outdoor use only installations: the smoke release rate, the convective and chemical heat release rate and content, velocity and temperature of the released vent gases were not be measured.		N/A
9.3.3	Test samples were installed as shown in Figure 9.2 in proximity to an instrumented wall section that is 3.66-m (12-ft) tall with a 0.3-m (1-ft) wide horizontal soffit (under surface of the eave shown in Figure 9.2).		N/A
	The sample was mounted on a support substrate and spaced from the wall in accordance with the minimum separation distances. The wall and soffit were constructed with 19.05-mm (3/4-in) plywood installed on wood studs and painted flat black.	The test was to cover outdoor use as well, however, gypsum was used.	M
	The instrumented wall extended not less than 0.49-m (1.6-ft) horizontally beyond the exterior of the target BESS units.		C
	If the manufacturer requires installation against non-flammable material, the test setup may include manufacturer recommended backing material between the unit and plywood wall.	16-mm gypsum wall board was used. The test was to cover outdoor use as well, however, gypsum was used.	M
	The No. 24-gauge or smaller, Type-K exposed junction thermocouple array on the walls extended to the surface of the soffit.		C
9.3.4	Target BESS were installed on each side of the initiating BESS in accordance with installation specifications. The physical spacing between BESS units (both initiating and target) were the minimum separation distances specified.		C
9.7	**Unit level test report**		

UL 9540A, Edition 4,			
Clause	Requirement + Test	Result - Remark	Verdict
9.7.1	Installation type tested:	Non Residential: outdoor ground mounted, indoor floor mounted.	C
9.7.2	Testing is intended to represent more than one installation type.	See Test Item Description in beginning of this report.	C
9.7.3	a. Unit manufacturer name and model number (and whether UL 9540 compliant);		C
	b. Number of modules in the initiating BESS unit		C
	c. BESS construction features;	See Attachment C See Critical Components Table ☐ See Also “Description of components employed within the module that impact propagation (fire protection features)” at the beginning of this report.	C
	d. Fire protection features/ detection/ suppression systems within unit	Fire protection features: Aerosol Fire detection: heat detector and smoke detector However, the fire suppression system was installed but not activated at the request of Contemporary Amperex Technology Co Limited	C
	e. Module voltages corresponding to the tested SOC;	See Table	C
	f. Thermal runaway initiation method used;	See Attachment C	C
	g. Location of the initiating module within the BESS unit;	See Attachment C	C
	h. Diagram and dimensions of the test setup including mounting location of the initiating and target BESS units, and the locations of walls, ceilings, and soffits;	See Attachment C	C
	i. Observation of any flaming outside the initiating BESS enclosure and the maximum flame extension;	See Table	C
	j. Chemical and convective heat release rate versus time data;	See Table 11 See Attachment G	C
	k. Separation distances from the initiating BESS unit to target walls	See Attachment C	C

UL 9540A, Edition 4,			
Clause	Requirement + Test	Result - Remark	Verdict

	l. Separation distances from the initiating BESS unit to target BESS units	See Attachment C	C
	m. The maximum wall surface and target BESS temperatures achieved during the test and the location of the measuring thermocouple;	Tables 5 and 6	C
	n. The maximum ceiling or soffit surface temperatures achieved during the indoor or outdoor wall mounted test and the location of the measuring thermocouple;	Table 6	N/A
	o) The maximum incident heat flux on target wall surfaces and target BESS units;	Table 7	C
	p) The maximum incident heat flux on target ceiling or soffit surfaces achieved during the indoor or outdoor wall mounted test;	Table 7	N/A
	q. Flammable gas generation and composition data;	See Attachment F See Tables 7, 8, 9, and 10	C
	r. Peak smoke release rate and total smoke release data.	See Table 12 See Attachments F	C
	s. Indication of the activation of integral fire protection systems and if activated the time into the test at which activation occurred;	Table 13	C
	t. Observation(s) of flying debris or explosive discharge of gases;	See Table 15	C
	u. Observation of re-ignition(s) from thermal runaway events	See Table 16	C
	v. Observation(s) of sparks, electrical arcs, or other electrical events;	See Table 15	C
	w. Observations of the damage to: 1) The initiating BESS unit; 2) Target BESS units; 3) Adjacent walls, ceilings, or soffits;	See Table 16	C
	x. Video of the test.		C
9.8	**Performance at Unit level testing**		
9.8.1	Installation level testing in Section 10 was not required if the following performance conditions outlined in Table 9.1 are met during the unit level test.		P
Non-Residential Installations – Indoor floor mounted:			
	a) Flaming outside the initiating BESS unit is not observed;	No flaming observed	P
	b) Surface temperatures of modules within target BESS units do not exceed the cell venting temperature;	Max surface temperature 29 ℃ didn't exceed the cell venting temperature 168 ℃	P

UL 9540A, Edition 4,			
Clause	Requirement + Test	Result - Remark	Verdict

	c) For BESS units intended for installation in locations with combustible constructions, surface temperature measurements on wall surfaces do not exceed 97 ℃ (175 ℉) rise above ambient;	Max wall surface temperature 29 ℃ didn't exceed 97 ℃ rise above ambient	P
	d) Explosion hazards are not observed, including deflagration, detonation or accumulation (to within the flammability limits in an amount that can cause a deflagration) of battery vent gases;	No explosion observed	P
	e) Heat flux in the center of the accessible means of egress did not exceed 1.3 kW/m^2.	Measured heat flux 0 kW/m^2 didn't exceed 1.3 kW/m^2	P
Non-Residential Installations – Outdoor ground mounted:			
	a) If flaming outside of the unit is observed, separation distances to exposures were determined by greatest flame extension observed during test.	No flaming observed	P
	b) Surface temperatures of modules within target BESS units do not exceed the cell venting temperature;	Max surface temperature 29 ℃ didn't exceed the cell venting temperature 168 ℃	P
	c) For BESS units intended for installation in locations near combustible construction, surface temperature measurements on wall surfaces do not exceed 97 ℃ (175 ℉) rise above ambient;	Max wall surface temperatures 29 ℃ didn't exceed 97 ℃ rise above ambient	P
	d) Explosion hazards are not observed, including deflagration, detonation or accumulation (to within the flammability limits in an amount that can cause a deflagration) of battery vent gases;	No explosion observed	P
	e) Heat flux in the center of the accessible means of egress did not exceed 1.3 kW/m^2.	Measured heat flux 0 kW/m^2 didn't exceed 1.3 kW/m^2	P

Table 1 – Specified Unit charging and discharging parameters			
Charging:		**Discharging:**	
Current (CC), A	140	Current (CC), A	140
Standard Full Charge Voltage, Vdc	3.6V per cell	End of discharge voltage, Vdc	2.8V per cell
End of charge current, A	N/A*	Discharging Test Ambient, ℃	0~55
Refer to Attachment A for charge/discharge profiles. *Charging is to continue till the voltage of a single cell reaches 3.6V			

Table 2 - Test Initiation Details	
Test Date	2022.07.04
Test Start Time (HH:MM:SS)	10:52:59
Initial Lab Temperature, ℃	29
Initial Relative Humidity % RH	82
Module OCV at Start of Test, Vdc	173.2

Table 3 – Approximate time of thermal runaway propagation through module			
Locations (Cell #)	**Event**	**Time**	**Temperature of the cell**
Cell 20	Vent	00:39:16	159
Cell 20	Thermal runaway	00:41:42	177
Cell 19	Thermal runaway	00:43:12	102

Table 4 – Test overview timeline		
Time (HH:MM:SS)	**Event**	**Description**
00:00:00	Test Start	The test started and the heater was turned on to heat the initiating cell (Cell 20) at a ratio of 4 ~ 7 ℃/min. See Figure(a)
00:39:16	Vent of initiating cell	Initiating cell (Cell 20) vented at around 159 ℃ measured through T2-1 by an indication of sudden dip in cell's temperature curve. See Figure(b)
00:41:42	Initiating cell Thermal runaway	Initiating cell (Cell 20) was at around 177 ℃ measured through T2-1. The temperature of cell 20 began to increase in an uncontrollable manner. See Figure (c)
00:43:12	2nd cell Thermal runaway	Temperature of the cell increased in an uncontrollable Thermal runaway propagated to nearby cell (cell 19) See Figure (d)
02:00:00	Test end	Data acquisition was stopped. The units were left in the test overnight and with the temperature data collected and the sample was See Figure (g)

Table 5 - Maximum Temperatures in Target Units					
Cell vent temperature from cell test data, ℃			168		
Target Unit 1		**Target Unit 2**		**Target Unit 3**	
Module Location No.	Temperature (℃)	Module Location No.	Temperature (℃)	Module Location No.	Temperature (℃)
Module-1	29	Module-1	29	Module-1	28
Module-2	28	Module-2	28	Module-2	28
Module-3	28	Module-3	27	Module-3	28
Module-4	29	Module-4	29	Module-4	29
Module-5	28	Module-5	28	Module-5	28
Module-6	28	Module-6	29	Module-6	28
Module-7	28	Module-7	29	Module-7	28
Module-8	29	Module-8	29	Module-8	28

Table 6 - Maximum Temperatures on Instrumented Wall					
Ambient Temperature: 29 ℃					
UL 9540A performance criteria, Ambient + 97 ℃: 126 ℃					
Height, mm	Maximum Temperature (℃)	Height, mm	Maximum Temperature (℃)	Height	Maximum Temperature (℃)
15.2	28	136.8	28	258.4	29
30.4	28	152	28	273.6	29
45.6	28	167.2	28	288.8	29
60.8	29	182.4	28	304	29
76	28	197.6	28	319.2	29
91.2	29	212.8	28	334.4	29
106.4	28	228	28	349.6	29
121.6	29	243.2	29	364.8	29
Note: Temperatures are measured constantly and then averaged every 60-seconds					

UL 9540A, Edition 4,			
Clause	Requirement + Test	Result - Remark	Verdict

Table 7 – Heat Flux Measurements			
Summary of maximum heat flux in target units		Summary of maximum heat flux measured on instrumented wall	
Maximum Heat Flux, kW/m²			
Target Module No.: 3 in the targe unit-1	0	Heat Flux Gauge No.	kW/m²
Target Module No.: 3 in the targe unit-2	0	Front wall 85-mm high, 5#	0
Target Module No.: 4 in the targe unit-2	0	Front wall 110-mm high, 6#	0
Target Module No.: 3 in the targe unit-3	0	Side wall 85-mm high, 10#	0
Target Module No.: 4 in the targe unit-2	0	Side wall 110-mm high, 11#	0
Egress path measurement:			0

Table 8 – Gases measured and measurement methods used in unit level testing			
Measurement Method	**Gases Measured**	**Chemical Formula**	**Gas Type**
Flame Ionization Detection (FID)	Total Hydrocarbons	-	Hydrocarbons
Solid-state Hydrogen Sensor	Hydrogen	H_2	
Non-dispersive infrared spectroscopy (NDIR)	Carbon Dioxide	CO_2	Carbon Containing
	Carbon Monoxide	CO	Carbon Containing
~~[ ] Fourier-Transform Infrared Spectrometer (FTIR)~~	~~Acetylene~~	~~C_2H_2~~	~~Hydrocarbons~~
	~~Ethylene~~	~~C_2H_4~~	~~Hydrocarbons~~
	~~Methane~~	~~CH_4~~	~~Hydrocarbons~~
	~~Methanol~~	~~CH_3OH~~	~~Hydrocarbons~~
	~~Propane~~	~~C_3H_8~~	~~Hydrocarbons~~
	~~Formaldehyde~~	~~CH_2O~~	~~Hydrocarbons (Aldehydes)~~
	~~Hydrogen Bromide~~	~~HBr~~	~~Hydrogen Halides~~
	~~Hydrogen Chloride~~	~~HCl~~	~~Hydrogen Halides~~
	~~Hydrogen Fluoride~~	~~HF~~	~~Hydrogen Halides~~
	~~Ammonia~~	~~NH_3~~	~~Nitrogen Containing~~
	~~Hydrogen Cyanide~~	~~HCN~~	~~Nitrogen Containing~~
# - This table was modified to reflect the gases measured during testing.			

Table 9 - Gas generation periods	
Time	**Condition**
From the venting point 00:39:16 to the end of test 02:00:00	Pre-Flaming
	~~Flaming~~
External Flaming of Gas	
Condition	**Duration (hh:mm:ss)**
External Flaming of Vent Gases:	N/A

Table 10 – Summary of battery gas volumes for deflagration hazard calculations				
Gas Component	Gas Type	During Pre-flaming (L)	During Flaming (L)	Minimum detectable flow rate(LPM)
Total Hydrocarbons (Propane Equivalent)	Hydrocarbons	284	No flaming	0.65
Carbon Dioxide	Carbon Containing	0.23	No flaming	0.26
Carbon Monoxide	Carbon Containing	7.51	No flaming	0.85
Hydrogen	Hydrogen	121.8	No flaming	6.44

Table 11 – Smoke and heat release rate			
Heat Release Rate (HRR)		**Smoke Release Rate (SRR)**	
Peak Chemical HRR (kW)	No flaming observed	Maximum SRR (m^2/s)	0.23
Peak Convective HRR, (kW)	No flaming observed	Total Smoke Released (m^2)	69.12

Table 13 - Module OCV voltage measurement comparison before and after testing			
Module Location In Rack	OCV Prior to Test (V)	OCV Post Test (V)	Difference (V)
1	173.2	173.1	0.1
2	173.2	173.2	0
3	173.2	155.1	18.1
4	173.2	173.1	0.1
5	173.2	173.1	0.1
6	173.2	173.2	0
7	173.2	173.2	0
8	173.2	173.2	0

Table 14 – Other Observations during Unit test			
	Observed, Yes/No	Comments/Location	
Flaming outside of Unit	N/A	Length of flame:	N/A
Flying debris	N/A	-	
Explosive discharge of gas	N/A	-	
Sparks or electrical arcs	N/A	-	

Table 15 - Post Test Observations	
Thermal runaway behaviour	No further thermal runaway after the test was completed.
Re-ignitions	No re-ignition occurred
Explosions	No explosion occurred
Other Observations	N/A

	TABLE: Critical components information				
Object / Part No.	**Manufacturer/ trademark**	**Type / model**	**Technical data**	**Standard**	**Mark(s) of conformity**
Cell	CONTEMPORARY AMPEREX TECHNOLOGY CO LIMITED	CB2W0, CB310	3.2Vd.c., 280Ah	UL 1973	MH 62898
Module	CONTEMPORARY AMPEREX TECHNOLOGY CO LIMITED	M52280-E, M52280-P	166.4V 280Ah	-	-
Unit Enclosure	CONTEMPORARY AMPEREX TECHNOLOGY CO LIMITED		Material: Galvanized sheet Thickness: ≥1mm 2280mm(H)*1300mm(W)*1300mm(D)	-	-
Liquid chiller	AIR INTERNATIONAL SHANGHAI CO., LTD	BTMS-80-ES	170 - 275 Va.c., 50/60Hz, 266mm*1040mm*1202mm, 2.2MPa, Maximum input power: 5kW, Maximum input current: 30 Aa.c. 8kW, -40 to 60 ℃, IP56 (control box)	UL 471	UL SA45615
Liquid chiller (Alternative)	Kelvin New Energy Technology Co., Ltd.	BTMS-80-ES	170-275 Va.c., 50/60Hz, 272mm*1039mm*1203mm, 2.2MPa, Maximum input power: 4.5kW, Maximum input current: 27Aa.c. 8kW, -40 to 60 ℃, IP56 (control box)	UL 471	UL SA45847
Gas Detector	NEXCERIS	241029	3-16Vd.c, Ø 28.6 x 25.4 [mm]	IEC 61010, EN60326-1	Intertek, 5016770
Heat Detector (Alternate)	APOLLO FIRE DETECTORS LTD	55000-142	Supply voltage: 9-33 Vd.c., 0 ℃ to 60 ℃, Detection of temperature: 76.7 ℃	UL 521	UL S5053
Smoke Detector (Alternate)	APOLLO FIRE DETECTORS LTD	55000-326	Supply voltage: 9-33 Vd.c., 0 ℃ to 60 ℃	UL 268	UL S5022
Detector base (Alternate)	APOLLO FIRE DETECTORS LTD	45681-256	Supply voltage: 9-33 Vd.c., 0 ℃ to 68 ℃	UL 268	UL S5022
Heat Detector (Alternate)	APOLLO FIRE DETECTORS LTD	4106-1004	Supply voltage: 9-33 Vd.c., -20 ℃ to 90 ℃, Detection of temperature: 65 ℃	AS 7240.5	SAI GLOBAL: SMK40168

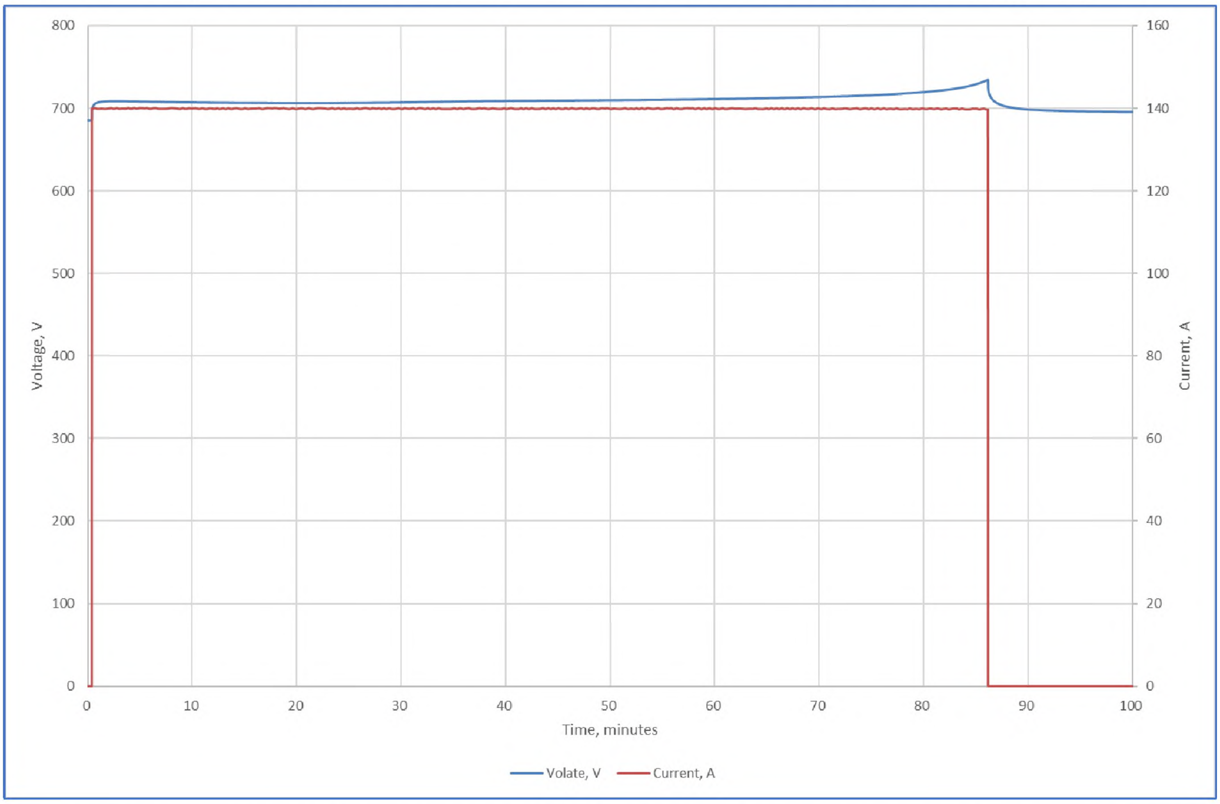
UL 9540A, Edition 4,			
Clause	Requirement + Test	Result - Remark	Verdict

Smoke Detector (Alternate)	APOLLO FIRE DETECTORS LTD	4106-1001	Supply voltage: 9-33 Vd.c., -20 ℃ to 60 ℃	AS 7240.7	SAI GLOBAL: SMK40168
Detector base (Alternate)	APOLLO FIRE DETECTORS LTD	4106-1011	Supply voltage: 9-33 Vd.c., 0 ℃ to 68 ℃	AS 7240	SAI GLOBAL: SMK40168
Heat Detector	APOLLO FIRE DETECTORS LTD	55000-121	Supply voltage: 9-33 Vd.c., -20 ℃ to 90 ℃, Detection of temperature: 65 ℃	EN54-5	LPCB: 010p/05
Smoke Detector	APOLLO FIRE DETECTORS LTD	55000-316	Supply voltage: 9-33 Vd.c., -20 ℃ to 60 ℃	EN54-7	LPCB: 010q/11
Detector base	APOLLO FIRE DETECTORS LTD	45681-246	Supply voltage: 9-33 Vd.c., 0 ℃ to 68 ℃	EN54	LPCB: 010
Heat Detector (Alternate)	POTTER ELECTRIC SIGNAL CO LLC	PAD100-HD	Supply voltage: 24 Vd.c., 0 ℃ to 66 ℃	UL521	UL S24776
Smoke Detector (Alternate)	POTTER ELECTRIC SIGNAL CO LLC	PAD100-PD	Supply voltage: 24 Vd.c., 0 ℃ to 49 ℃	UL268	UL S24776
Detector base (Alternate)	POTTER ELECTRIC SIGNAL CO LLC	PAD100-4DB	Supply voltage: 24 Vd.c., 0 ℃ to 49 ℃	UL268	UL S24776
Aerosol	FIREAWAY INC	Stat-X condensed aerosol generator, Model 100 E	Activated Alumina: CAS 1333-84-2 (Aluminum Oxide non-fibrous): 100g, -40 ℃ to 54 ℃, Supply voltage: 24 Vd.c.	UL/ULC 2775	UL EX15004
Aerosol (Alternative)	FIREAWAY INC	Stat-X condensed aerosol generator, Model 100 T	Activated Alumina: CAS 1333-84-2 (Aluminum Oxide non-fibrous): 100g, -40 ℃ to 54 ℃, Trigger temperature:70 ℃	AS/NZS 4487	CSIRO: afp-2284

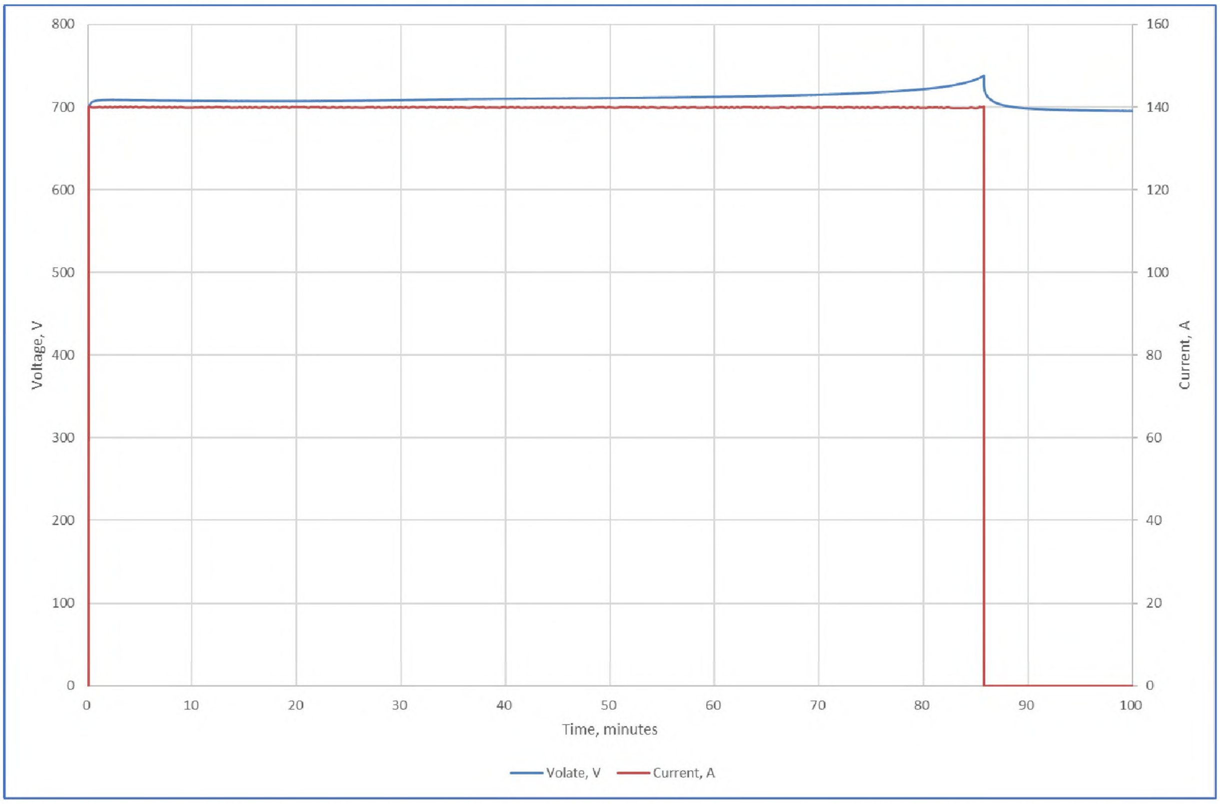
Aerosol (Alternative)	FIREAWAY INC	Stat-X condensed aerosol generator, Model 250MT	Activated Alumina: CAS 1333-84-2 (Aluminum Oxide non-fibrous): 197g, -40 ℃ to 54 ℃, Trigger temperature:70 ℃	SI 1998 No.1609 Reg 8(1), SI 1998 No.2271 Reg (6), SI 2001 No.0009 Reg 7(1), SI 2002 No. 2201 Reg 5(1) MGN 280	MCA, File reference: MS 47/11/1042
The material of cover for waterproof strip	CENTURY CREATION INTERNATIONAL	EPDM	Thickness:1.0mm Temperature: 60 ℃	UL 1973, IEC/EN 62477-1 Environment test	Tested with appliance VBD01J00452200004C
The material of cover for waterproof strip (Alternative	ASIA LANNERET SCIENCE & TECHNOLOGY CO LTD	EPDM-2015	Thickness:1.0mm Max.service temperature: 70 ℃	UL 157	UL MH60816
Internal connecting wires for HV	DONGGUAN NISTAR TRANSMITTING TECHNOLOGY CO INC	UL3932	2000 Vd.c., 125 ℃, 95mm2	UL 758	UL E214184
Lead wire for high voltage sampling circuit	DONGGUAN NISTAR TRANSMITTING TECHNOLOGY CO INC	UL3932	2000 Vd.c., 125 ℃, 1mm2	UL 758	UL E214184
Power cable for auxiliary power supply	DONG GUAN NISTAR TRANSMITTING TECHNOLO G Y CO., INC.	UL3666	2.5/4 mm2 XLPE 105 ℃ 600 Va.c.	UL 758/UL1581	UL E214184

Note: the alternate component in this report is only for reference only. UL didn't test the product with alternate component and no follow-up service evaluation is being performed for UL9540A products.

Attachment A: Sample Charging, OCV and SOC Measurement Profiles - (*Pages **28** through **27***)



From the bottom up, module 1 to module 4 of the initiating unit, series connected, charge to 100% SOC

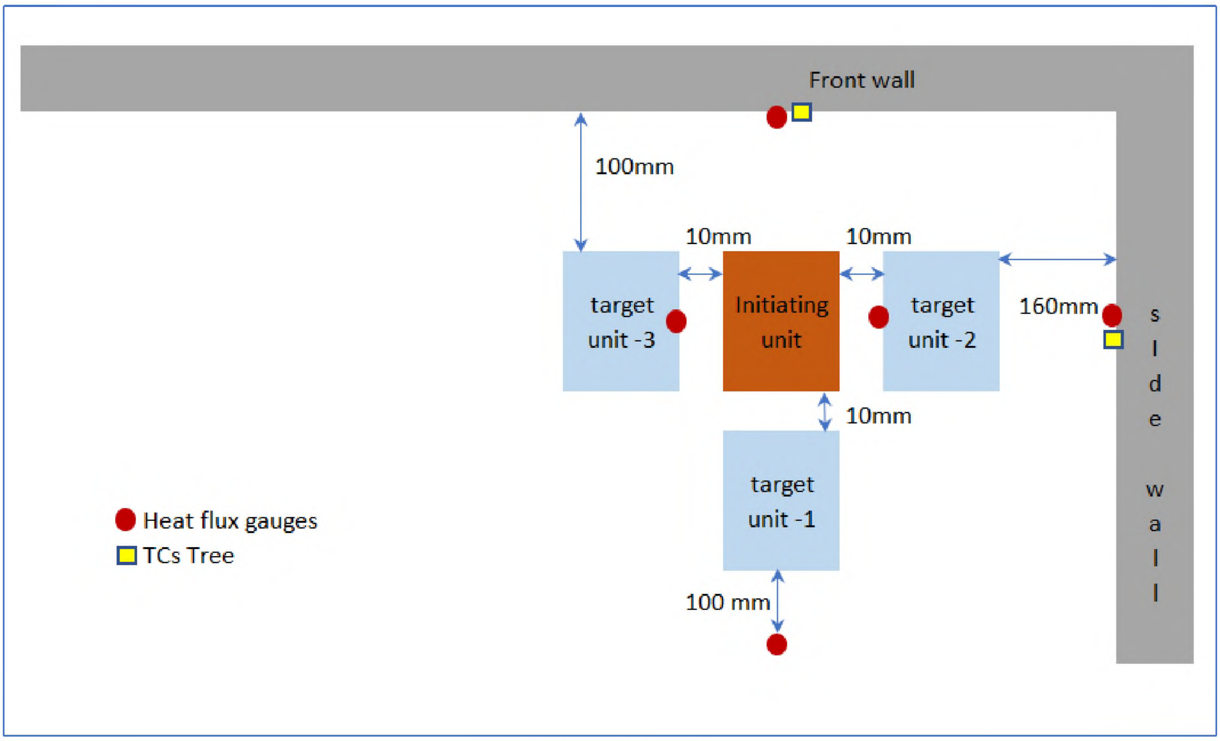


From the bottom up, module 5 to module 8 of the initiating unit, series connected, charge to 100%SOC

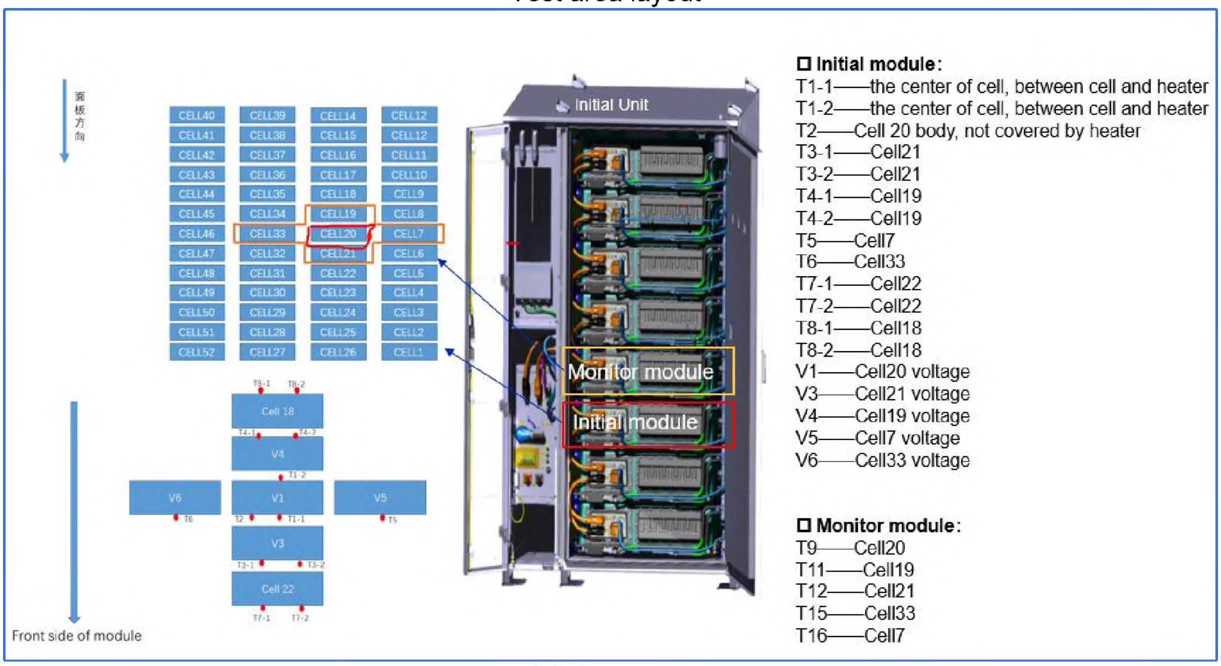
Attachment B: BESS (including module and any integral fire detection and suppression systems) Construction Photos/Diagrams - (*Pages **28** through **29***)

BESS Construction Photos

Attachment C: BESS and Equipment Instrumentation and Test Installation Layout Photos/Diagrams - (*Pages **30** through **31***)

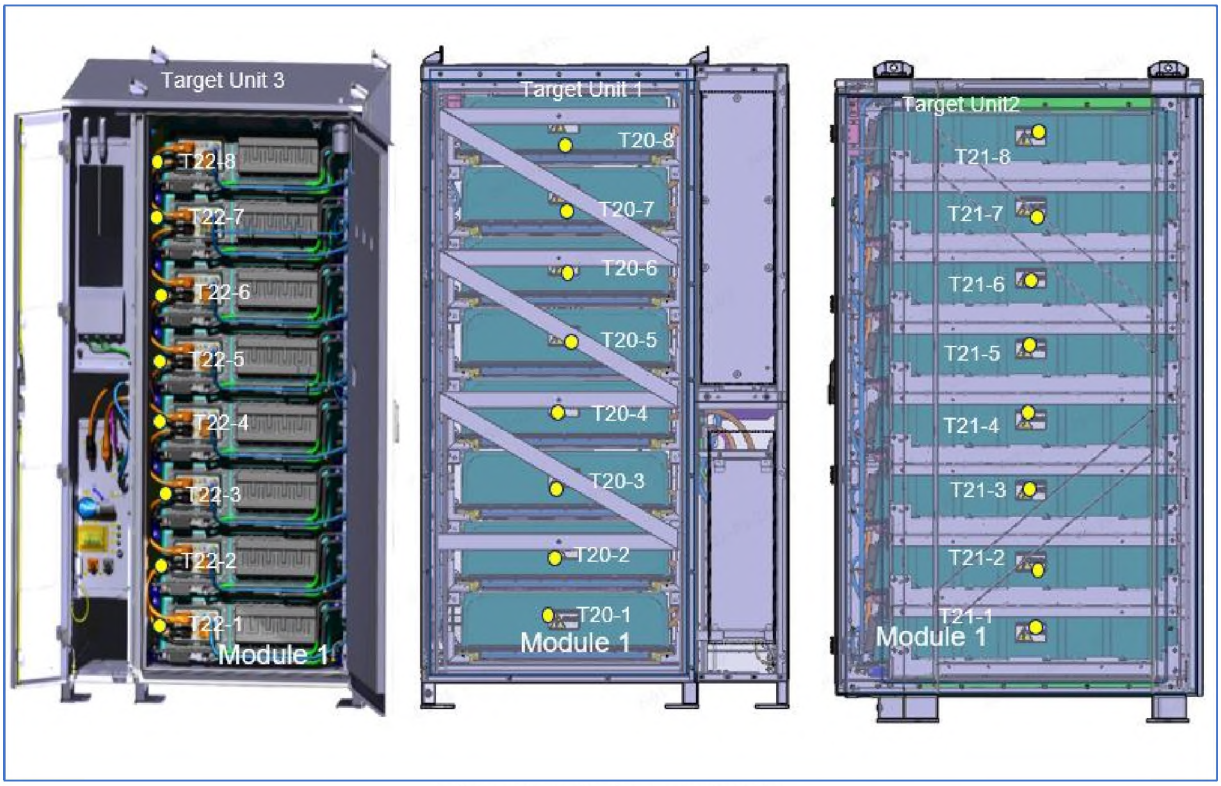


Test area layout[4]



TC Location

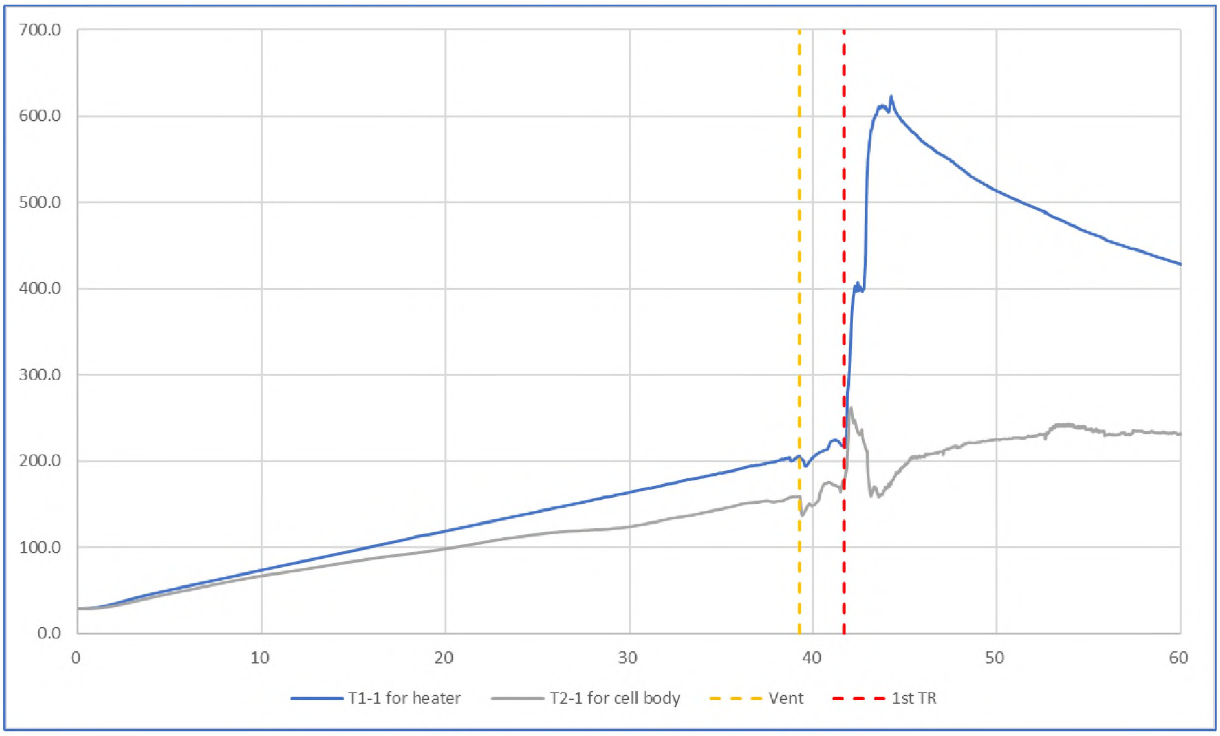
[4] The egress gauge location was selected by client. The lower gauge of the front wall also can be on behalf of the egress path heat flux.



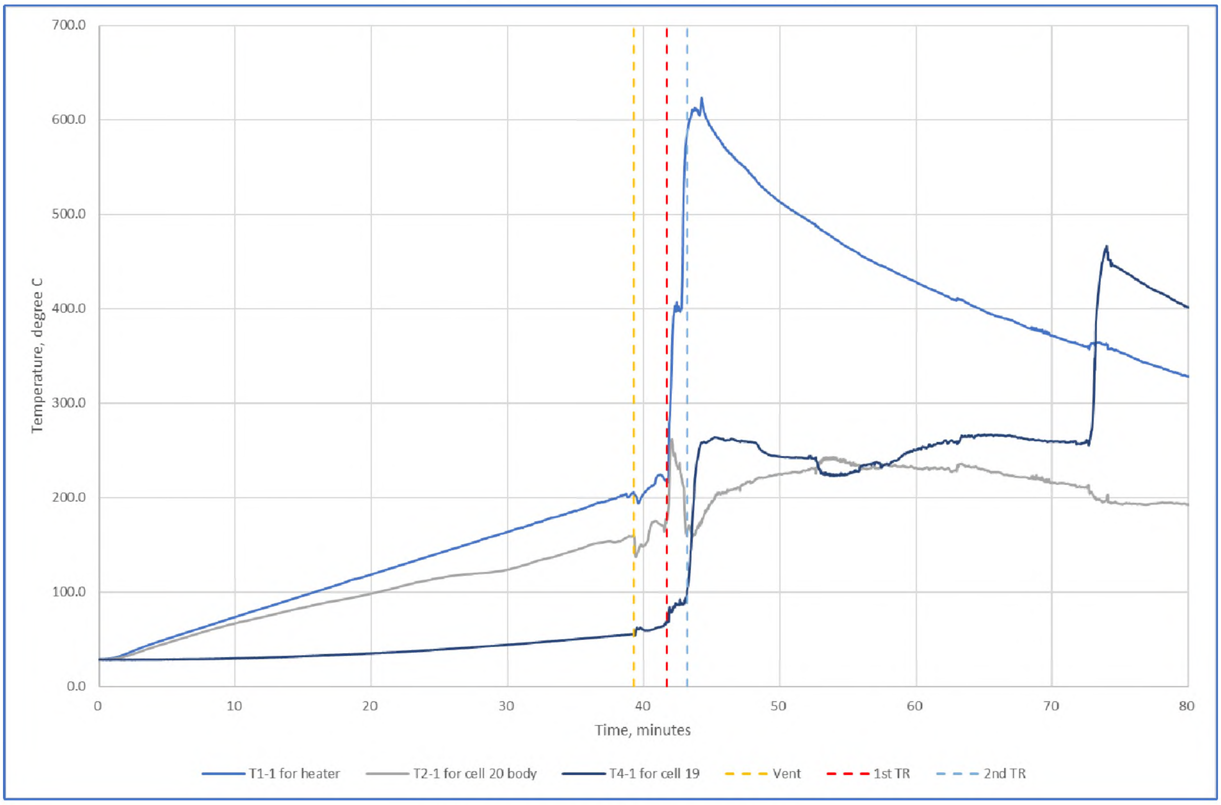
TC location in the target units

Test area photo

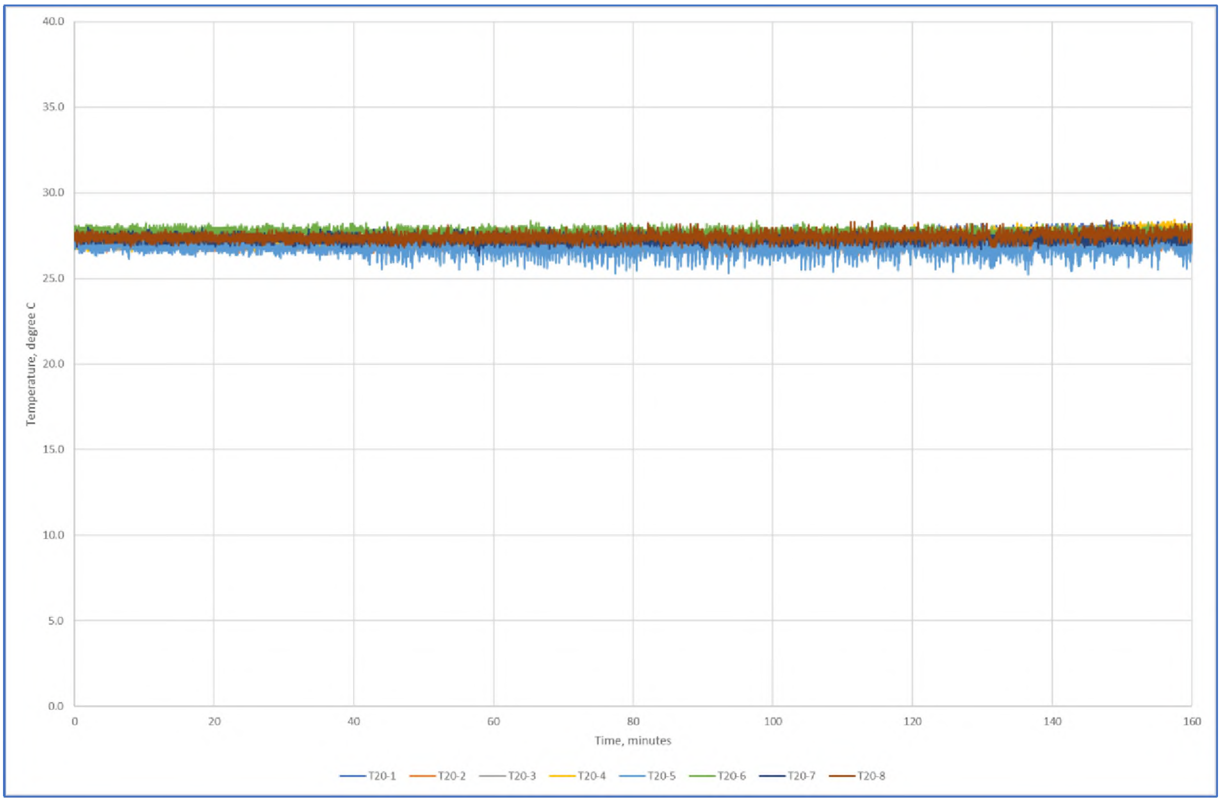
Attachment D: Temperature Profiles and Heat Flux Measurements During Testing (Initiating Cell and Module, Target Modules, Wall Surfaces, etc. - (*Pages **32** through **35***)



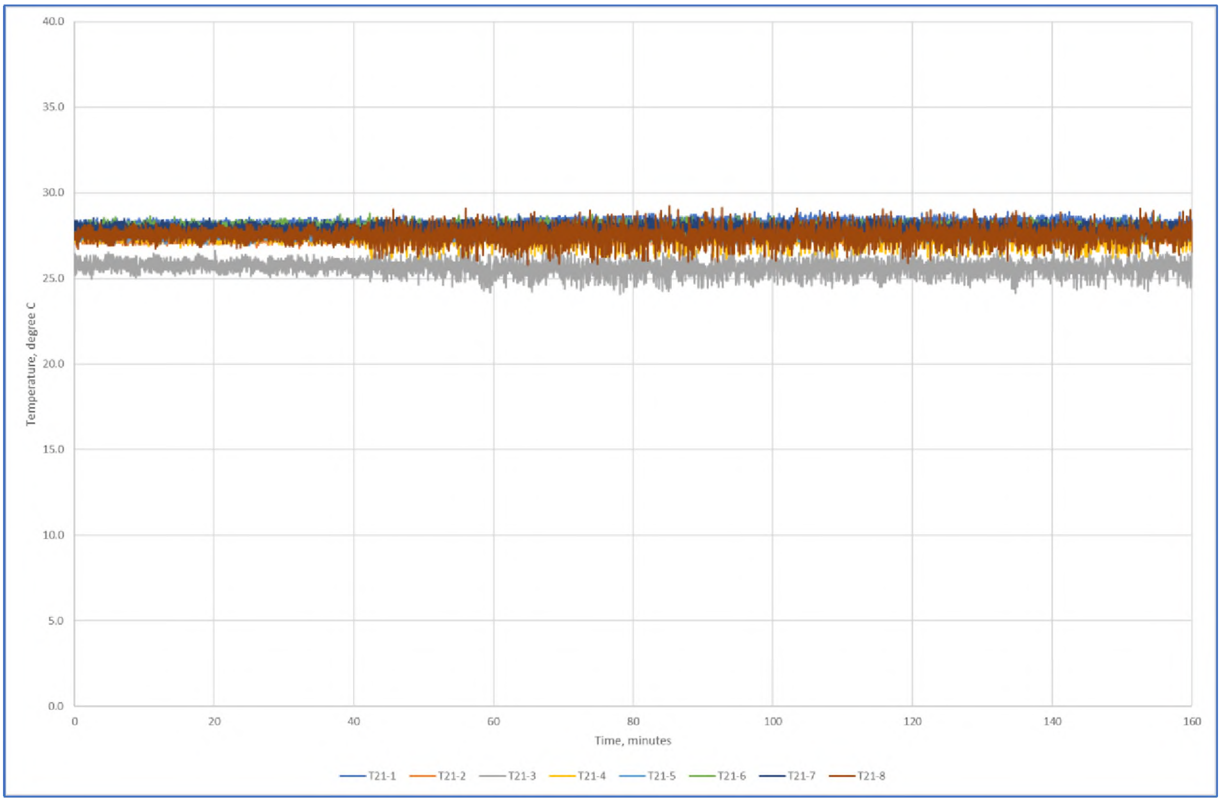
Initiating cell vent and thermal runaway



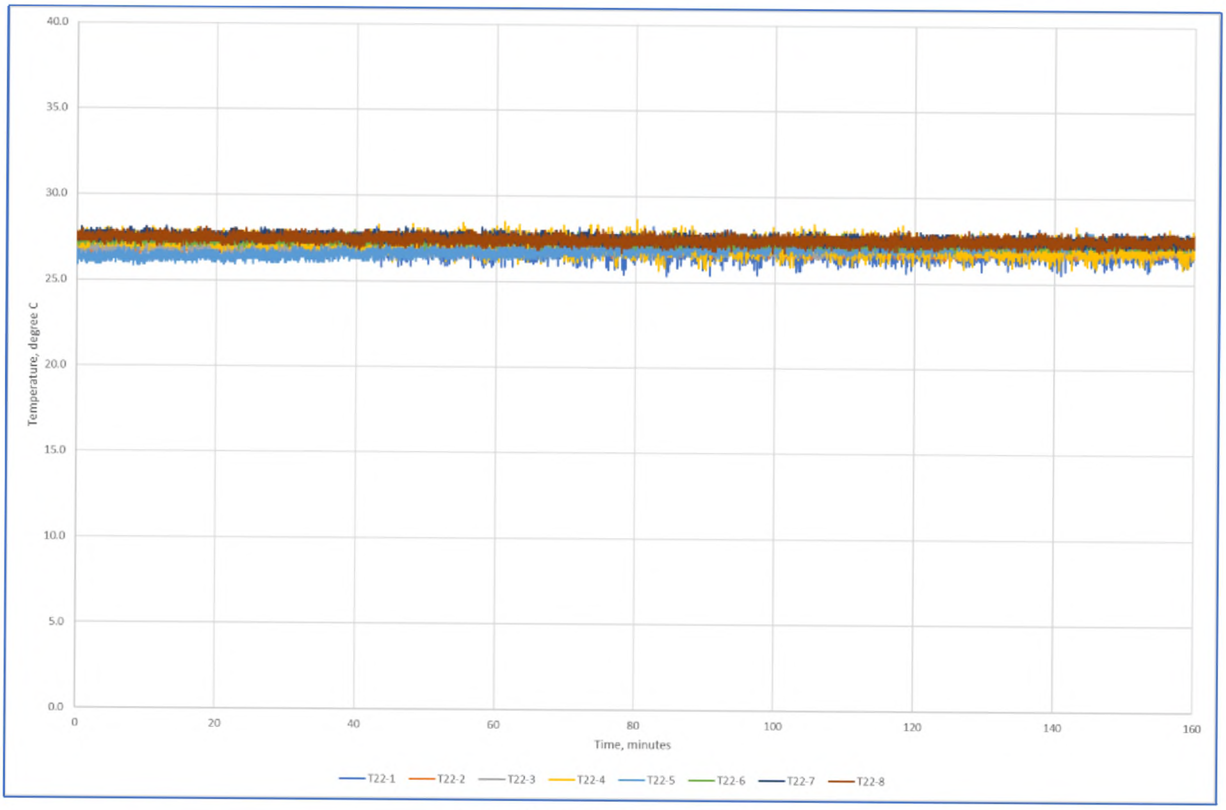
Initiating module temperature



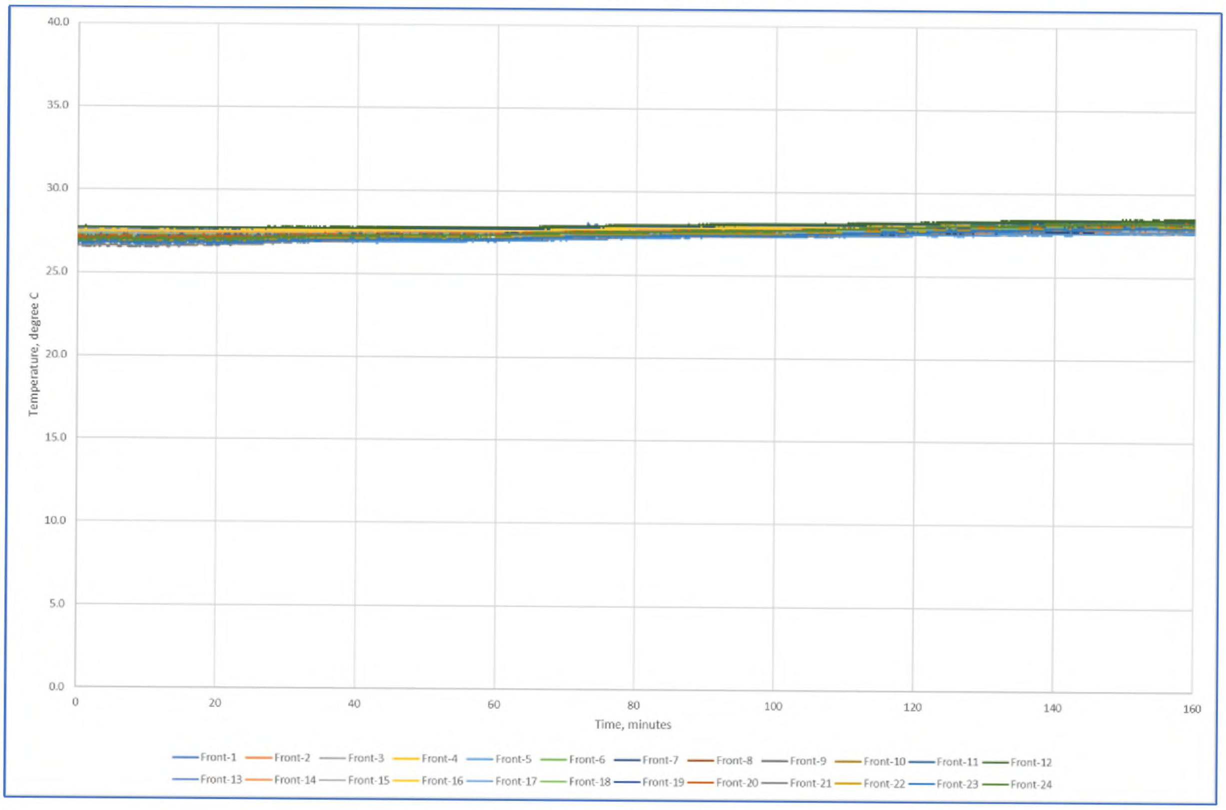
Target unit-1 temperature



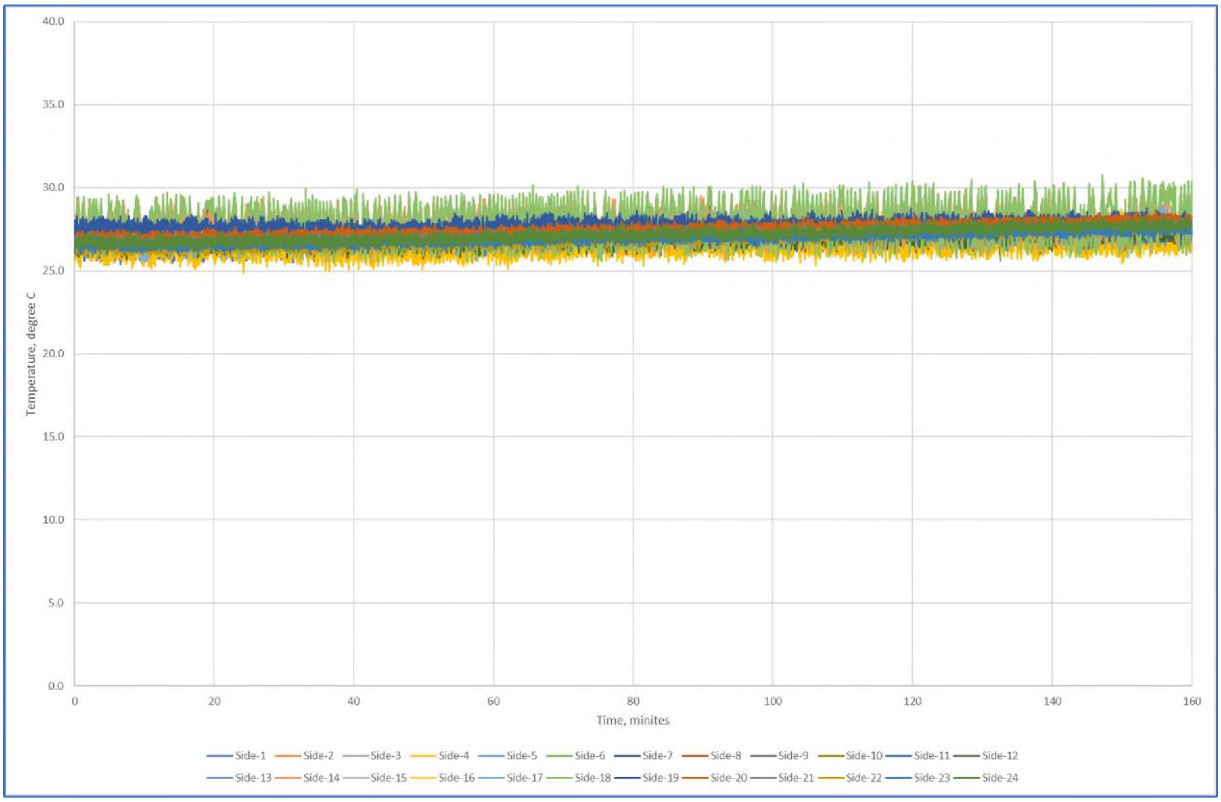
Target unit-2 temperature



Target unit-3 temperature



Front wall temperature



Side wall temperature

Attachment E: BESS Unit Testing and Post Testing Photos - (*Pages **36** through **38***)

(a) Test Start
[00:00:00]

(b) Vent of initiating cell
[00:39:16]

(c) Initiating cell thermal runaway
[00:41:42]

(d) Cell 19 thermal runaway
[00:43:12]

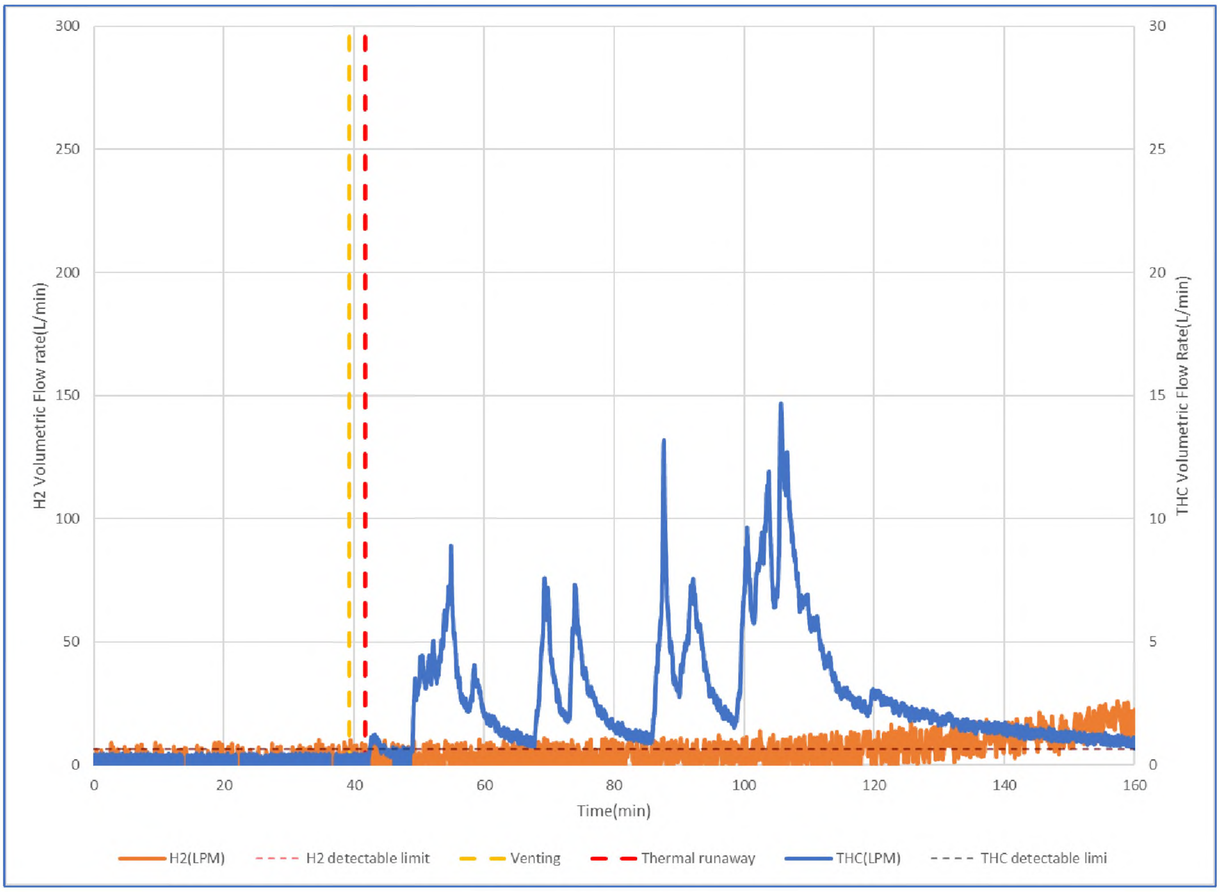
(e) Cell 21 thermal runaway
[00:44:19]

(f) Cell 18 thermal runaway
[01:13:24]

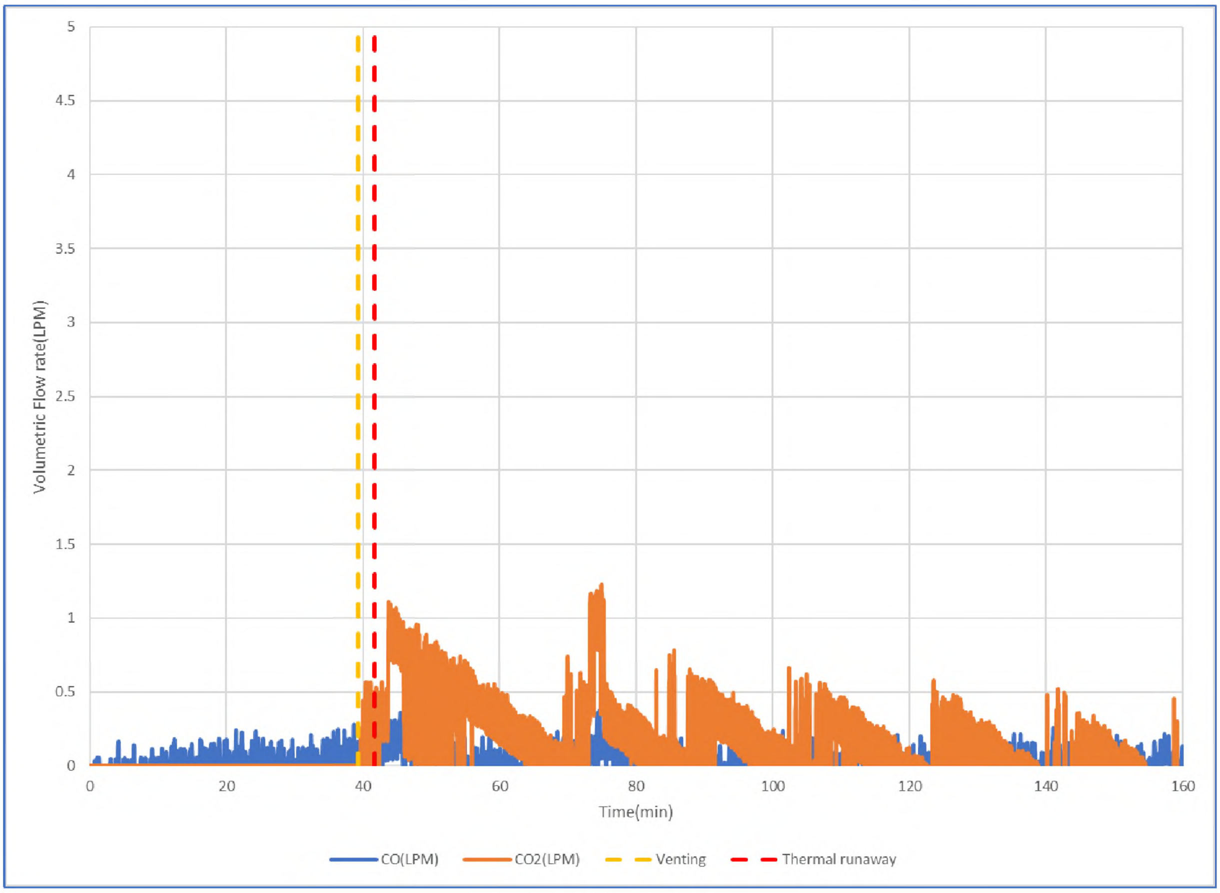
(g) Event description
[02:00:00]

	
Photos after test	

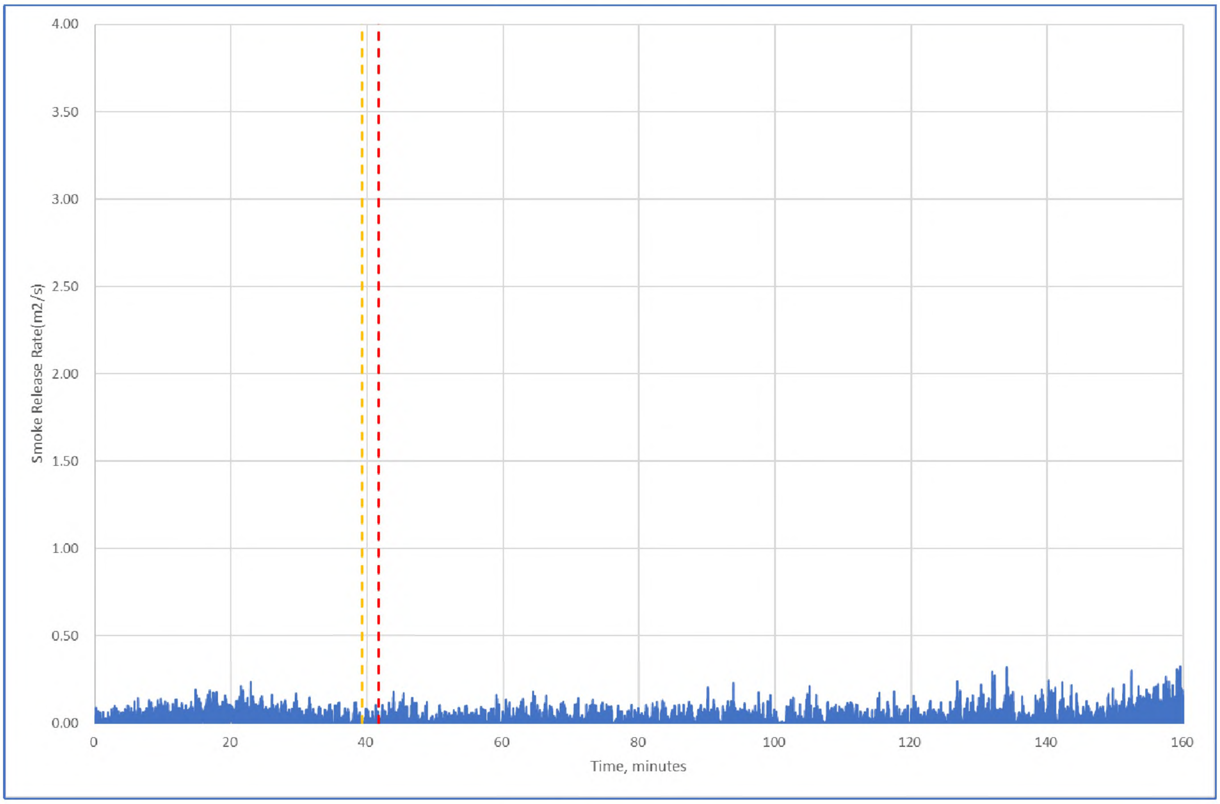
Attachment F: BESS Unit Gas Flow Rate and Heat Release and Smoke Release Profiles - (*Pages **39** through **41***)



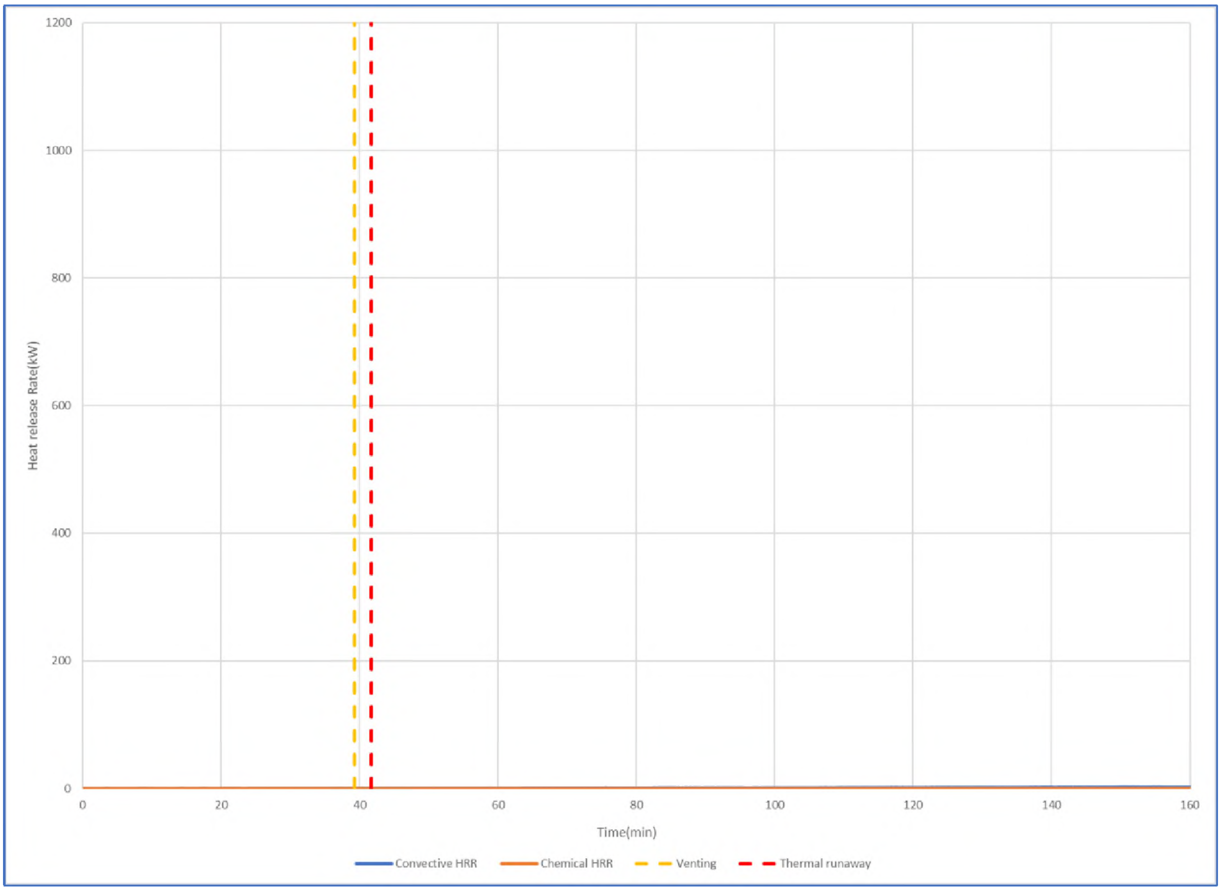
THC, H2 flow rates



CO, CO2 flow rates



Smoke release rate



Chemical heat release rate (No flaming observed)

Noot

In dit document zijn gedeeltes onleesbaar gemaakt op grond van artikel 5 van de Wet open overheid:

- Art. 5.1 lid 2 onderdeel e Woo (naam)
- Art. 5.1 lid 2 onderdeel e Woo

Exhibit 4

2024 White Paper

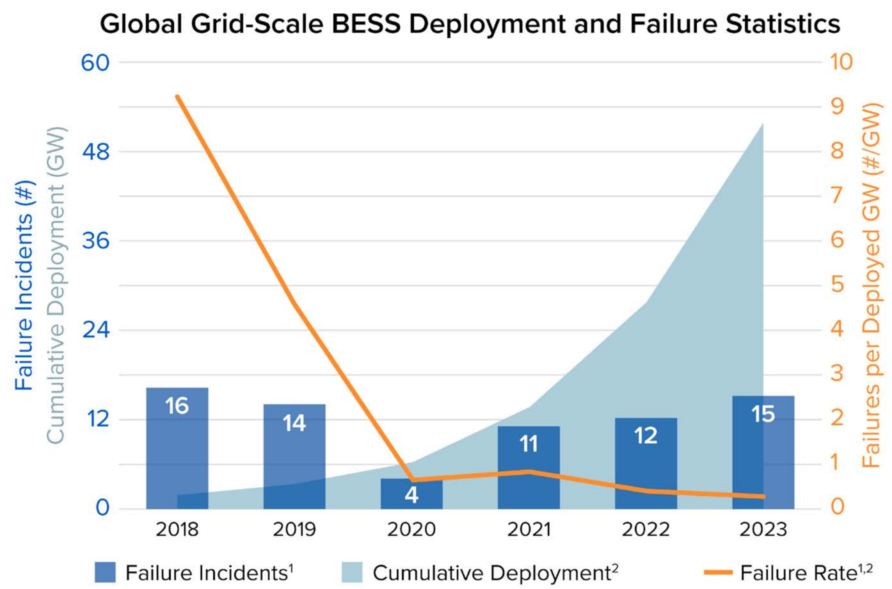
Insights from EPRI's Battery Energy Storage Systems (BESS) Failure Incident Database

Analysis of Failure Root Cause

TABLE OF CONTENTS

INTRODUCTION

The global installed capacity of utility-scale battery energy storage systems (BESS) has dramatically increased over the last five years. While recent fires afflicting some of these BESS have garnered significant media attention, the overall rate of incidents has sharply decreased,[1] as lessons learned from early failure incidents have been incorporated into new designs and best practices. Between 2018 and 2023, the global grid-scale BESS failure rate has dropped 97%. The battery industry continues to engage in R&D activities to improve prevention and mitigation measures, including development of a better understanding of the diverse causes of BESS failures.



Sources: (1) EPRI Failure Incident Database, (2) Wood Mackenzie. Data as of 12/31/23.

Figure 1. *Global Grid-Scale BESS Deployment and Failure Statistics*

Several entities compile information on battery fires that have occurred in various products (e.g., mobile, stationary, consumer product) categorized by differing battery technologies (e.g., lead acid, lithium ion). EPRI has produced the most comprehensive compilation of stationary BESS incidents, called the EPRI BESS Incident Database,[2] based on publicly accessible underlying data. Other notable databases include UL's Lithium-Ion Battery Incident Reporting[3] and EV FireSafe.[4]

1 *Technology Innovation Spotlight: Lithium Ion Battery Fires in the News.* EPRI, Palo Alto, CA: 2023. 3002028411.

2 BESS Failure Incident Database. This was formerly known as the BESS Failure Event Database. It has been renamed to the BESS Failure Incident Database to align with language used by the emergency response community. An 'incident' according to the Federal Emergency Management Agency (FEMA) is an occurrence, natural or man-made, that requires an emergency response to protect life or property, while an 'event' is a planned, non-emergency activity. The use of incident is prevalent, for example, in referring to the Incident Command, or Incident Command System used by public and private agencies to coordinate incident management operations, https://www.fema.gov/pdf/emergency/nrf/nrf-glossary.pdf.

3 Lithium-ion Battery Incident Reporting. UL Solutions. https://www.ul.com/insights/lithium-ion-battery-incident-reporting.

4 EV FireSafe Database. https://www.evfiresafe.com/.

The UL Lithium-Ion Battery Incident Reporting encompasses incidents caused by utility-scale, C&I, and residential BESS, as well as EVs, e-mobility, and consumer products. This database focuses exclusively on lithium ion technologies. EV FireSafe tracks EV and electric micro-mobility fires involving (though not necessarily *caused* by) the traction battery, and categorizes incidents by cause. Both the UL Lithium-Ion Battery Incident Reporting and EV FireSafe provide statistics and figures, but do not disclose details of individual failures or sources.

There is currently no public resource that categorizes BESS incidents by cause of failure. This information would provide industry-level insights on common and uncommon failure modes, and would help to prioritize needed mitigation technology R&D. This knowledge is particularly important because individual incident details and root cause information are not always easily accessible, but are crucial to improve safety and understand risk. Failure classification can help determine the role of different components of a BESS, from controls to battery cell/module, in contributing to an incident and in preventing future incidents. No current federal, state, or local jurisdiction requires incident reporting. Even in cases where detailed root cause investigations are conducted, legal barriers often prevent the results from being shared publicly. New York state encouraged Original Equipment Manufacturers (OEMs) to disclose root cause analyses (RCAs) after failure incidents, but stopped short of including a requirement for disclosure in their pending update[5] to the fire code.

This report is intended to address the failure mode analysis gap by developing a classification system that is practical for both technical and non-technical stakeholders. Once categorized in a standardized manner, the aggregated failure data was analyzed to better understand trends in how, why, and how infrequently BESS fail, and to provide recommendations for future safety improvements.

5 New York State Inter-Agency Fire Safety Working Group: Fire Code Recommendations. NYSERDA. Feb 6, 2024. https://www.nyserda.ny.gov/-/media/Project/Nyserda/Files/Programs/Energy-Storage/Draft-New-York-State-Inter-Agency-Fire-Safety-Working-Group-Fire-Code-Recommendations.docx.

METHODOLOGY

This report relies on data from EPRI's BESS Failure Incident Database along with findings from incident reports and root case analyses and expert interviews conducted by the authors to build robust descriptions of each event. Each incident from the database is categorized through a biaxial framework to allow for analysis of two distinct failure facets. BESS failures were classified by a) the root cause of failure (design; manufacturing; integration, assembly & construction; or operation); and b) by the element of the BESS that experienced the failure (cell/module, controls, or balance of system). The study examines the proportion of failures sharing a root cause or responsible element, the relationship between root cause and the element experiencing failure, and the trends in failure type and rate over time. Results from this analysis will inform the industry's efforts to optimize safety research and product development.

The BESS Failure Incident Database

EPRI's BESS Failure Incident Database is the main source of data for this report. The database was initiated in 2021 following the series of lithium ion BESS fires in South Korea and the Surprise, AZ, incident in the US. The database gathers information on stationary BESS failure events for commercial and industrial (C&I) and utility-scale BESS. This database defines utility-scale BESS as a system that is interconnected to the grid, with no capacity limitations, while C&I systems could include behind-the-meter installations. Residential energy storage system failures are not tracked by this database and were not considered in this report.

It contains incidents as far back as 2011 and continues to be updated with new incidents as they occur. The focus of the database is on occurrences that had a wider public health and safety risk or impact, rather than on operational failures where no additional risk to personnel or equipment was present or likely. EPRI defines *failure incident* as an occurrence which resulted in increased safety risk, *caused by* a BESS system or component failure rather than an exogenous cause of failure (e.g., wildfire impacting the BESS).

The database captures incidents occurring globally and cites information from publicly available sources, including media reports, published root cause analyses (RCA), and corporate press releases. Source documents are identified by active searching of global English-language media, and passive collection of reports through keyword flagging on internet websites and RSS feeds. Crowdsourced information that can be verified through publicly available documentation is also incorporated. EPRI has used academic publications, and collaborated with other organizations tracking failures, to ensure all publicly known stationary BESS events are captured. However, many incidents are not reported in news media, especially before 2018-19 when there was a renewed industry focus on safety. There is no guarantee that the database captures every relevant BESS failure incident, nor that all project data related to an incident is captured. Despite these caveats, this remains the most comprehensive stationary BESS failure database available.

Data Collection

At the time of writing, the database contained 81 incidents. Of these, 26 incidents had sufficient information to assign a root cause and to identify the element that experienced failure. Certain incidents had published root cause analysis reports that explicitly noted the cause of failure. The remaining incidents were classified based on engineering judgement by subject matter experts at EPRI, TWAICE, and Pacific Northwest National Laboratory (PNNL). The authors reviewed publicly available technical details and interviewed other industry experts involved in failure incident analysis. No proprietary information was discussed in these interviews nor used in the classification of the incidents.

Transparency on the cause of BESS failures continues to be limited. Battery OEMs and BESS integrators are often reluctant to disclose the cause of failure, and many investigation reports are not released to the public. In several instances, legal complications prevent site owners or manufacturers from divulging information about the nature of the failure. Aggregation and anonymization by a third-party can encourage disclosure of such information to support safety research advancement.

Classification of Failure Incidents

Incidents can result from a variety of causes, such as water intrusion, retrofitting errors, operating conditions, coolant leaks, temperature stress, quality control, component manufacturing defects and other factors. For meaningful analysis, these causes were grouped into classifications. Each failure incident with sufficient information was classified by root cause and by failed element. Definitions for each classification are provided below:

Root Cause:

- **Design**
  A failure due to planned architecture, layout, or functioning of the individual components or the energy storage system as a whole. Design failures include those due to a fundamental product flaw or lack of safeguards against reasonably foreseen misuse.
- **Manufacturing**
  A failure due to a defect in an element of an energy storage system introduced in the manufacturing process, including but not limited to, the introduction of foreign material into cells, forming to incorrect physical tolerances, or missing or misassembled parts.
- **Integration, Assembly & Construction**
  A failure due to poor integration, component incompatibility, incorrect installation of elements of an energy storage system or due to inadequate commissioning procedures.
- **Operation**
  A failure due to the charge, discharge, and rest behavior of the energy storage system exceeding the design tolerances of an element of an energy storage system or the system as a whole. Operational failures include, but are not limited to, incorrect sensing of voltage, current, temperature, and other set point values, or operation above designed temperature, C-rate, state of charge, or voltage limits of the energy storage system.

Failed Element:

- **Cell/Module**
  A failure originating in the lithium ion cell or battery module, the basic functional unit of the energy storage system. It consists of an assembly of electrodes, electrolyte, casing, terminal, and usually separators.[6]

6 IEC Glossary. https://www.electropedia.org/iev/iev.nsf/display?openform&ievref=482-01-01.

Cell failures usually begin with short circuits within the cell leading to eventual thermal runaway. They can originate from poor cell design, manufacturing defects, incorrect installation, or cell abuse.

- **Controls**
  A failure in the sensing, logic circuits, and communication systems. Control systems coordinate the operation of the ESS, including the battery management system (BMS), energy management system (EMS), plant controllers, and any subsystems. Controls failures include those due to control system incompatibility, incorrect installation of the control system, defects leading to errors in sensors or controls, or inappropriate operation limits.
- **Balance of System (BOS)**
  A failure in any of the elements of a BESS excluding the cells, modules, and controls. BOS typically comprises of, but is not limited to: busbars, cabling, enclosures, power conversion systems, transformers, fire suppression systems, HVAC, or liquid cooling systems.

An incident may have multiple failure elements or root causes; such incidents are assigned multiple classifications. The following example illustrates this classification methodology. The Elkhorn battery facility located at Moss Landing, CA, experienced a fire on September 20, 2022. The investigation report[7] was shared publicly by Tesla (the BESS manufacturer and integrator) and Pacific Gas & Electric (site owner). The investigation found that rainwater intrusion through the container caused electrical arcing within the system, leading to thermal runaway within one BESS unit on site. A water ingress point in the enclosure had been created when an umbrella valve had been dislodged during the improper installation of a vent shield. As a confounding factor, insulation loss alarms were not properly escalated to the operator. Two days after the initial insulation alarms were recorded, smoke and fire were reported to the fire department. Appropriate reporting of the insulation loss alarms could have prevented escalation of the initial failure into a fire that consumed the whole BESS unit. Therefore, the root cause was classified as both an integration, assembly & construction failure in the BOS and a design failure of the control system.

RESULTS

Results Overview

The following section contains insights from the 26 incidents that were classified. The distributions along the biaxial classification system are examined in detail. As described above, investigations into battery failures are often inconclusive, and there is a lack of transparency that further limits the sharing of lessons learned. The industry experts who provided additional information beyond public reports are based in the United States, so information on incidents in other parts of the world is more limited in this report.

7 Report: *Elkhorn Battery Energy Storage System Fire of September 20, 2022 - PGE Currents*. https://www.pgecurrents.com/articles/3833-report-elkhorn-battery-energy-storage-system-fire-september-20-2022.

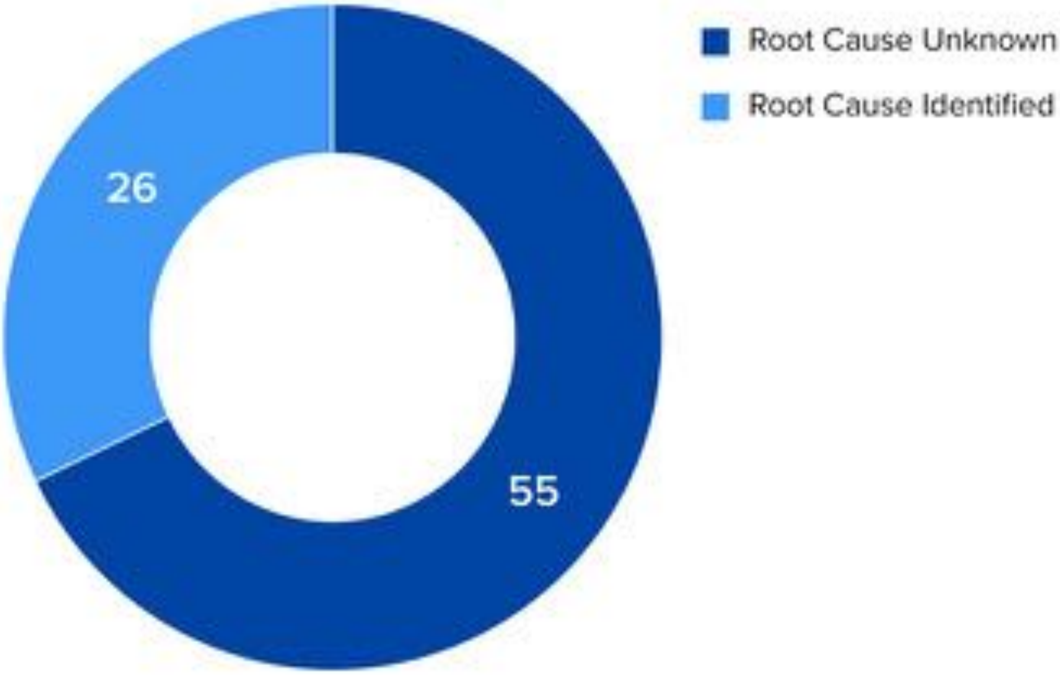


Figure 2. *Fraction of BESS Failures with Identified Cause*

Of the 9 incidents recorded in the BESS Failure Incident Database between 2011 and 2017, none were able to be classified, while 36% of incidents between 2018 and the present had root causes identified. The availability of root cause information starting in 2018 is an indication of both energy storage industry maturity as well as collective action and scrutiny on lithium ion BESS safety.

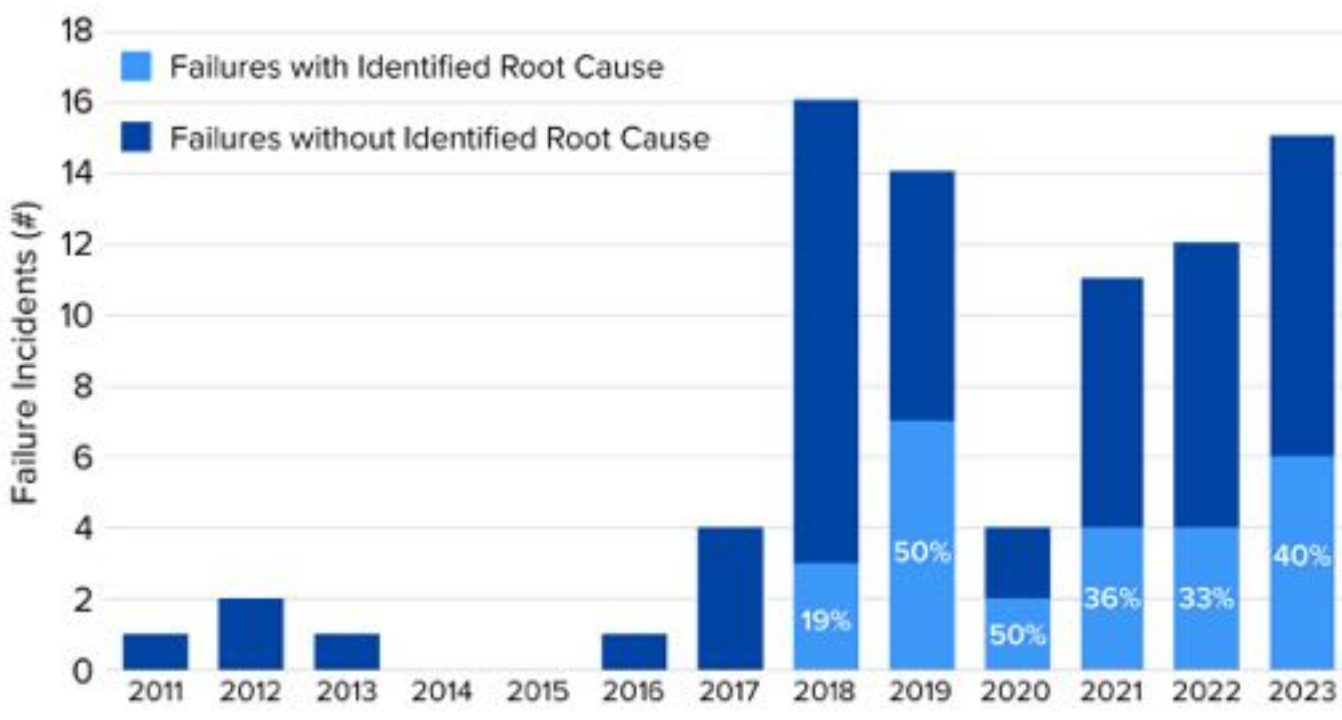


Figure 3. *BESS Failures with Identified Root Cause Over Time*

Between 2017 and 2018, the lithium ion BESS deployments increased by ~1 GW, more than doubling total global deployment, and signaling the advent of the commercial BESS industry.[8] The period between 2017-2019 also experienced a spike in BESS failure incidents. Of the 30 incidents in the database between 2018 and 2019, 27 occurred in South Korea. The Korean government had provided strong economic incentives for BESS, especially paired with solar PV generation. The number of installed BESS in South Korea rose from 30 in 2013 to 947 in 2018. The rapid deployment was not accompanied by robust safety standards and regulations, which contributed to the failures.[9] After the first spate of fires, the South Korean government investigated the incidents, and provided summarized findings for the failures in aggregate. Subsequent academic papers provided more detailed root cause analyses for individual incidents.[10]

In the United States, a fire and explosion at a BESS facility in Surprise, AZ in 2019 injured four firefighters. Following the incident, multiple root cause investigation reports were released publicly, and safety became a priority issue for the energy storage industry in the US. In the subsequent years, root cause investigations have occasionally been made public to support industry learnings. However, the number of unclassified incidents in the preceding figures are a clear indication of the continued challenges around failure data access and transparency.

Root Causes of Incidents

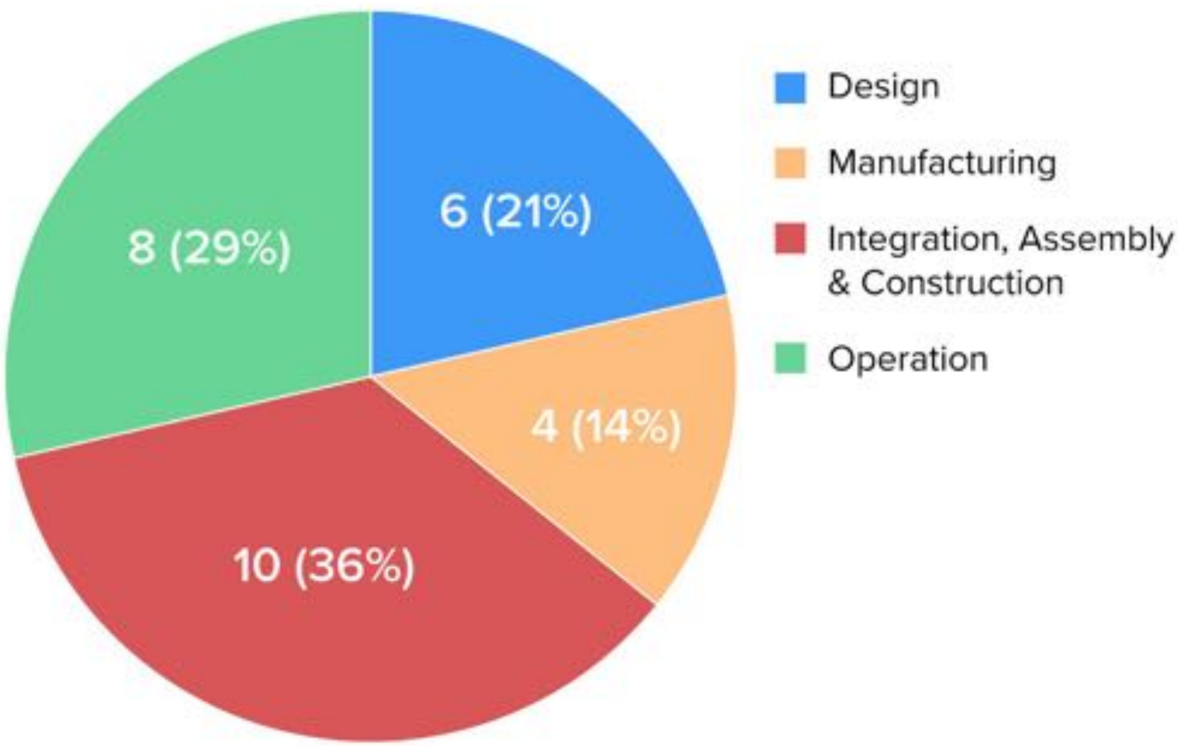


Figure 4. *Breakdown of BESS Failures by Root Cause*

8 WoodMackenzie Energy Storage Database. Accessed Apr 17, 2024.

9 Im, D-H and J-B Chung. Social construction of fire accidents in battery energy storage systems in Korea. *Journal of Energy Styorage,* Volume 71, 1 November 2023, 108192. https://doi.org/10.1016/j.est.2023.108192.

10 Na, Y-U and J-W Jeon. Unraveling the Characteristics of ESS Fires in South Korea: An In-Depth Analysis of ESS Fire Investigation Outcomes, *Fire,* 6(10), 389, 2023. https://doi.org/10.3390/fire6100389.

Figure 4 shows the root cause classification for the 26 incidents considered in the analysis. Note that two incidents were classified with dual root causes (Design as well as Integration, Assembly & Construction), and the discrepancy in total incidents is due to this double-counting. There is no clear phase across the product lifecycle that is particularly susceptible to failure, with all phases contributing to several failures. EPRI has also gathered information on failure incidents during manufacturing, transportation, and recycling of batteries, which can be found in the 'Other' table in the database.[11] These incidents were not considered for this analysis.

Integration, Assembly & Construction was the most common root cause of failure in this analysis. Figure 5 highlights the number of failures in the database that happen early in the project lifecycle. Referring back to Figure 1, deployment has increased significantly in recent years, and there are relatively few older BESS that are operational. This may be why there are not many recorded failure incidents of aged systems so far. It remains to be seen if this trend will be sustained as systems being installed today age over time. Regardless, the majority (72%) of failures where the system age is known happen during construction, commissioning, or within the first two years of operation. Integration, Assembly & Construction is a critical phase in BESS risk mitigation. This root cause is examined further in subsequent sections of this report.

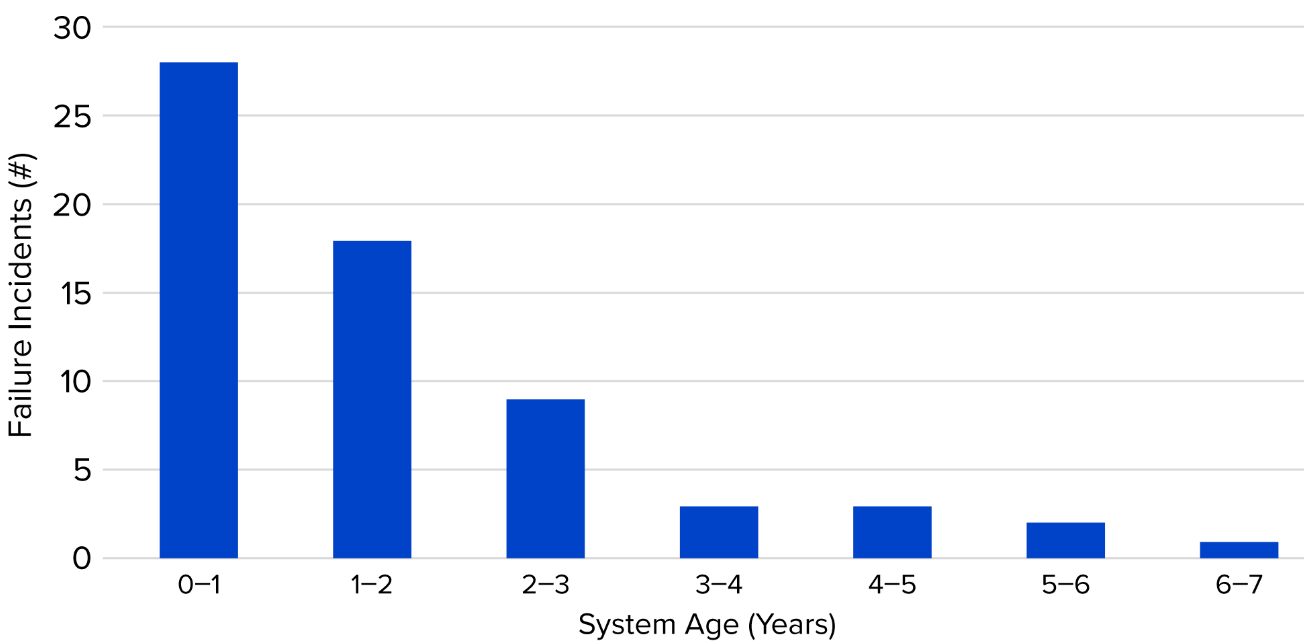


Figure 5. *BESS Age at Failure, where known*

11 BESS Failure Event Database.

Manufacturing as a root cause has the fewest failures attributed to it. This is most likely due to the difficulty in definitively identifying a manufacturing defect as a root cause with the loss of physical evidence after a fire or explosion. Earlier failures from 2018-2020 in particular may have involved cell or module manufacturing defects as a contributing factor. Several product recalls from major EV manufacturers during those years cited manufacturing issues by battery OEMs.[12,13] Some residential ESS products were also recalled during the same timeframe.[14] It is important to note that recalls do not definitively point to manufacturing issues, but indicate the probable failure cause. In recent years, more robust product standards such as Underwriters Laboratory (UL) 1973 (Standard for Batteries for Use in Light Electrical Rail Applications and Stationary Applications) and UL 1642 (Standard for Lithium Batteries) have improved the quality of manufactured batteries. Product certifications include quarterly and annual audits of factories to review quality control procedures, part inspection standards, and more. A recent report from Clean Energy Associates (CEA) summarizes findings from BESS factory quality audits. Of the identified issues in cell and module manufacturing, the majority were classified as minor issues, meaning they were not expected to impact safety in the short or long term.[15]

Failed Element

The distribution of failure sources across BESS elements (i.e. components) provides an insightful view of the vulnerabilities within the system.

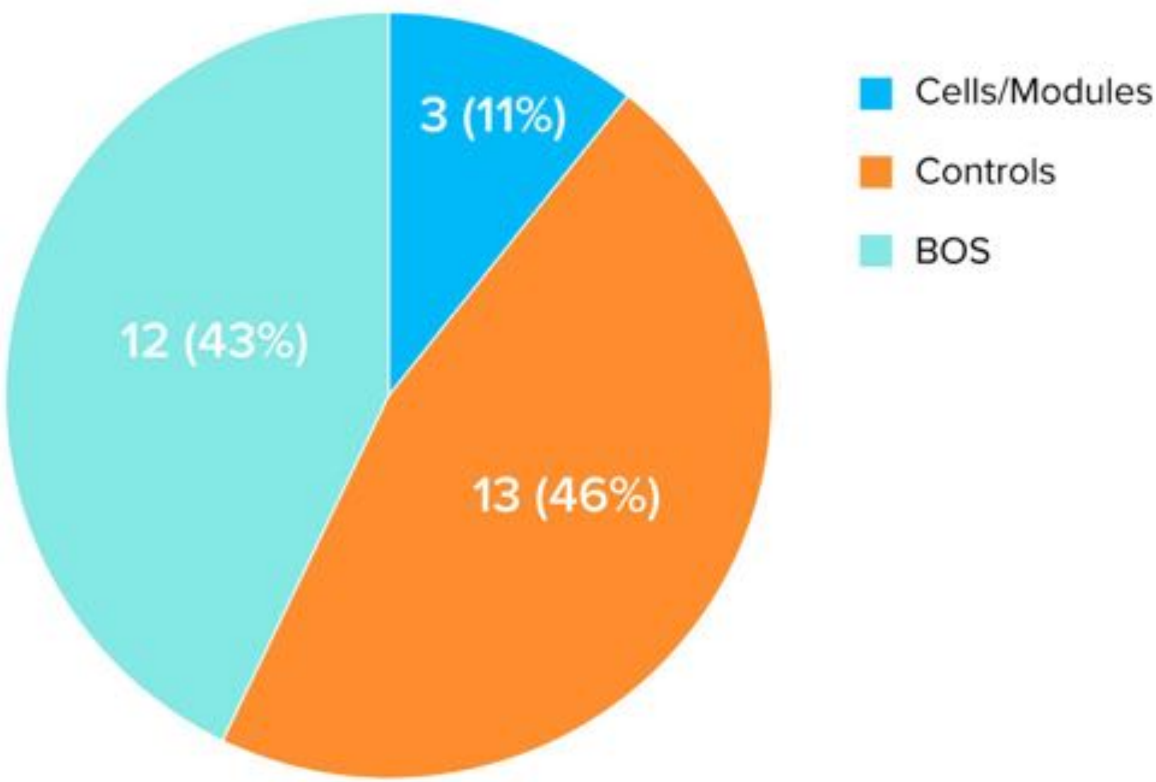


Figure 6. *Breakdown of BESS Failures by Failed Element*

12 Gitlin, J. Multiple recalls spark Fed investigation of LG's electric car batteries. *Ars Technica*, 2022. https://arstechnica.com/cars/2022/04/multiple-recalls-spark-fed-investigation-of-lgs-electric-car-batteries/.

13 De Chant, T. GM recalls every Chevy Bolt ever made, blames LG for faulty batteries. *Ars Technica*, 2021. https://arstechnica.com/cars/2021/08/gm-recalls-every-chevy-bolt-ever-made-blames-lg-for-faulty-batteries/.

14 United States Consumer Product Safety Commission. LG Energy Solution Michigan Recalls Home Energy Storage Batteries Due to Fire Hazard.

15 BESS Quality Report. February 2024. Clean Energy Associates Insights.

The BOS and controls account for the vast majority of failed components. The prevalence of BOS failures is corroborated by the recent CEA report cited above, which found that nearly 50% of quality assurance items were in the BOS. Only 3 incidents, or 11% of classified incidents, are attributed directly to the cells. However, it should be noted that many of the failures classified as controls were related to operational issues aimed at restricting cell state of charge (SOC), voltage and current, due to cell limitations. These were classified as controls failure rather than cell/module since the failures could have been prevented if more limited operational windows were maintained.

Biaxial Analysis

The following analysis looks at the combination of root cause and failed elements across the 26 incidents considered.

Figure 7. *Relationship between Root Cause and Failed Element*

1. ***Integration, Assembly & Construction and BOS***
   Integration is the most common root cause of BESS failures, and the vast majority of incidents with this classification involved BOS components. These components included DC and AC wiring, HVAC subsystems, and safety elements such as the fire suppression system. Lithium ion BESS contain components from multiple suppliers, which are not necessarily designed to work together. Integration is a critical part of the deployment and installation process to ensure all interfaces are compatible and functional. A 2021 incident in Australia at the Victoria Big Battery facility is an example of BOS failure due to assembly quality issues. During commissioning, a leak in the coolant system led to a fire that spread across two BESS units.[16]

2. ***Operation and Controls***
   Operation is the second most common root cause, and in all cases, the operation failure occurred in the controls system. Seven of these incidents occurred in 2018-2019 in South Korea, reflecting the early challenges in determining appropriate BESS operation limits for parameters such as voltage and SOC.

16 *Lessons Learned from Past Failures Around the World, Session 6: Responding to a Safety Event.* EPRI, Palo Alto, CA: 2023. https://www.sandia.gov/app/uploads/sites/163/2023/06/2023ESSRF_Session6.2_Srinivasan_Lakshmi.pdf.

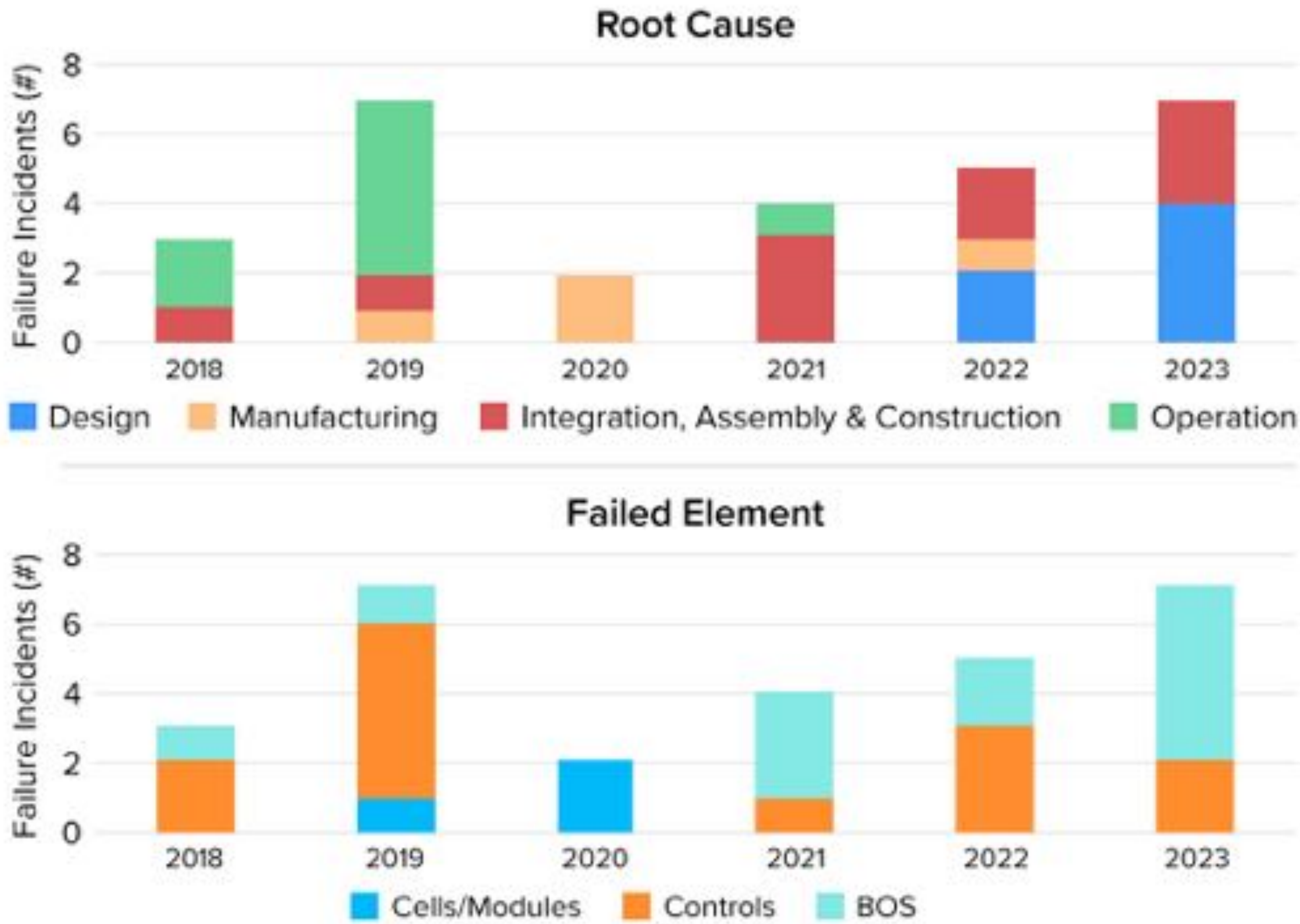


Figure 8. *Root Cause and Failed Element Trends Over Time*

Considering root cause trends over time, the bulk of operational failures occurred in 2018-2019 when a significant number of BESS installed in South Korea experienced fires. Many of these were classified as operational failures since the SOC just before incidents was higher than recommended limits. Investigation of the failures revealed that a significant fraction of those failures occurred when the SOC was above 90%.[17] It is possible that these failures could also be attributed to manufacturing or design issues with the cell, but there was not sufficient evidence to make that determination with confidence.

Integration-related failures have become more common. The vast majority of these failures are related to poor build quality in the BOS, whether it is AC or DC wiring, coolant systems, or safety systems such as water suppression piping. The CEA report corroborates these findings: 26% of inspected BESS units had defects in the fire suppression system, while 18% had thermal management system defects.[18] Both subsystems are critical for BESS safety. It is important to note that some of these failures occurred during the commissioning phase, when monitoring and communications were not online, thus allowing leaks or isolation failures to cascade into large-scale fires. Site-specific hazard assessments, monitoring, and procedures during commissioning are recommended to avoid failures. EPRI published an updated commissioning guide[19] in 2023 through the Energy Storage Integration Council (ESIC) that captures recommendations and lessons learned to improve safety.

While the core battery technology has been in commercial development since the 1990s, fully integrated BESS products arrived much later to market. BOS subsystems like cooling, and especially safety components are not yet

17 Na, Y-U and J-W Jeon. Unraveling the Characteristics of ESS Fires in South Korea: An In-Depth Analysis of ESS Fire Investigation Outcomes, *Fire,* 6(10), 389, 2023. https://doi.org/10.3390/fire6100389.

18 BESS Quality Report. February 2024. Clean Energy Associates Insights.

19 *ESIC Energy Storage Commissioning Guide*. EPRI, Palo Alto, CA: 2023. 3002013972.

mature. BESS products have rapidly evolved from walk-in containers assembled on-site to module, pre-integrated systems. There is a diversity of products, architectures, thermal management approaches etc., leading to integration challenges and the potential for incompatible interfaces or unexpected interactions between components.

As deployment increases, many more individuals and organizations are working on BESS for the first time. New products without long operational histories are entering the market. A lack of experience and training in integration and assembly could have contributed to the assembly and construction-related failures in the recent years. Designs may have flaws, or may not account for all operating and ambient conditions. For example, three of the four design-related failures in 2023 occurred due to same BOS design flaw in a BESS product. The enclosure design for systems in New York and Idaho allowed water intrusion into the battery compartment, leading to loss of isolation and thermal runaway. Global storage deployment is expected to grow exponentially, and many new entrants to the industry are expected. Sufficient training for manufacturers and integrators/developers and more extensive product quality control systems are needed to prevent integration, assembly, and construction failures going forward.

Mitigations and Recommendations

Reducing the risks associated with lithium ion BESS is a complex task. Safety must be embedded at every scale of a project, from material selection at the cell level to public health impacts at the community level. As illustrated by this analysis, safety must also to be considered at every phase of the project lifecycle, from design to operation to decommissioning. For an overview of related lithium ion BESS safety resources, including state-of-the-science documentation of safety technology and hazard assessments, visit EPRI's Storage Wiki Safety Page.[20]

The recommendations in this section focus on addressing the gaps identified in this report. These are not intended to be exhaustive. Preventative and mitigative measures against thermal runaway can take many forms, included components design/engineering, monitoring, procedural, and site-level analyses. A comprehensive view of risk mitigation options can be found in the ESIC Energy Storage Reference Hazard Mitigation Analysis.[21]

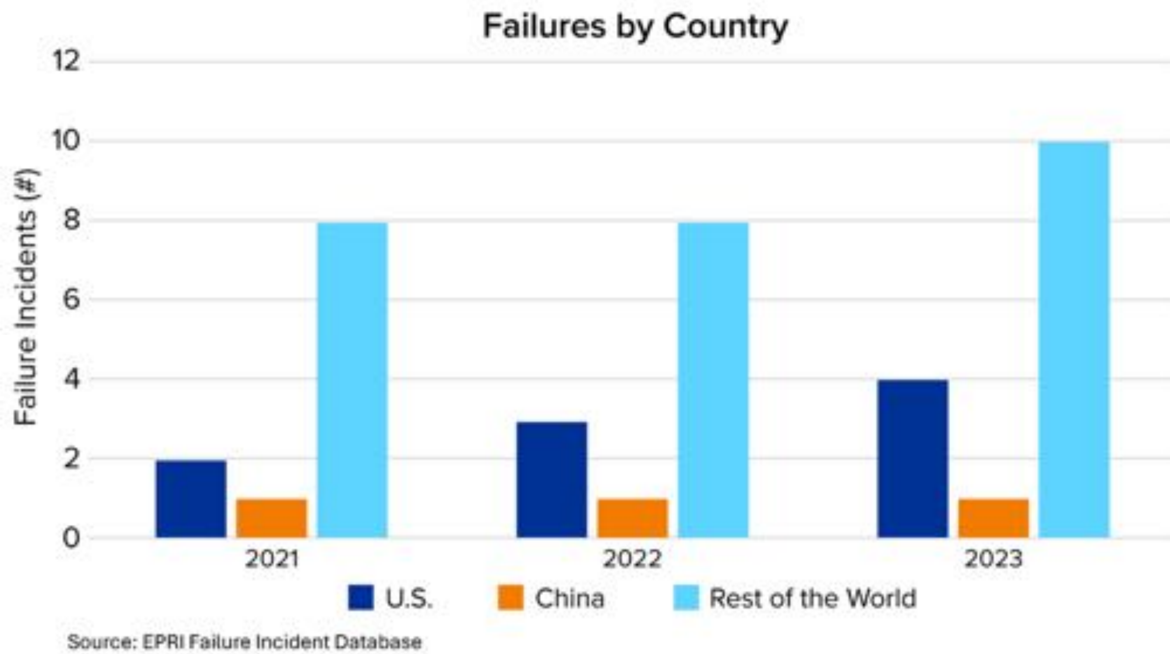
Table 1. *Mitigations and Recommendations for Each Root Cause*

ROOT CAUSE	FAILED ELEMENT	MITIGATIONS AND RECOMMENDATIONS
Design	Controls, BOS	• Compliance with relevant codes and standards (UL, NFPA). Latest revisions have incorporated lessons learned from past failures. • Site-specific hazard assessments to consider all risks and failures. • Robust sensing and monitoring to provide early alert for design failures.
Integration/Assembly/ Construction	BOS, Controls	• Workforce training and quality checks during energy storage commissioning and installation. • System-level failure analysis, especially for interfaces between components.
Manufacturing	Cell/Module, Controls	• Increased manufacturing quality controls. • Supplier quality verification. • Robust system specifications. • Factory acceptance testing.
Operation	Controls	• Battery monitoring and analytics to augment BMS operation, generating trends and predictive analyses to identify potential failures early.

20 Storage Safety. EPRI, Palo Alto, CA.
21 *ESIC Energy Storage Reference Fire Hazard Mitigation Analysis*. EPRI, Palo Alto, CA: 2021. 3002023089.

Looking Ahead

This analysis is the first look at BESS failure root causes in aggregate. For a significant fraction of the incidents, the root cause was unknown, highlighting challenges in transparency around BESS failures. Additionally, it is possible that there are BESS failures that have not been captured in the EPRI database. A comparison of deployments in energy capacity and reported failures in recent years by country points to a possible information gap. The number of failures is taken from the EPRI BESS Failure Incident Database, while installed capacity numbers are from Rho Motion Consulting.[22]



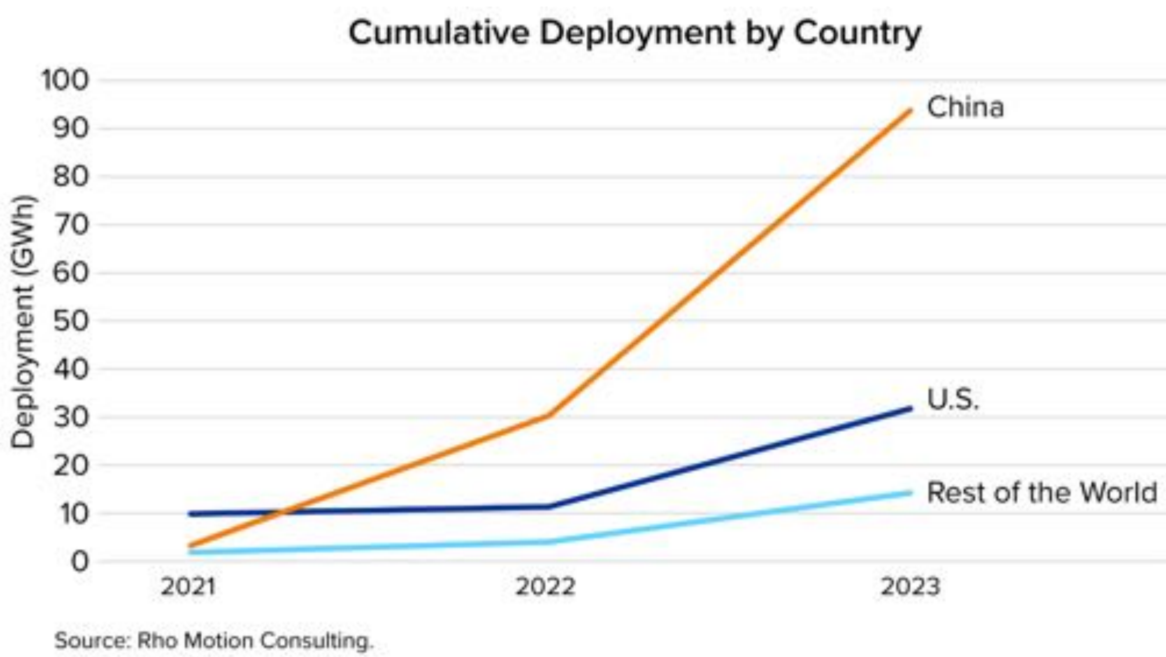


Figure 9. *Failures and Cumulative Deployment by Country*

22 Rho Motion Consulting. Battery Energy Stationary Storage Monthly Database.

EPRI and the other co-authors of this paper call for more transparency and data-sharing by the storage industry, especially of root cause investigations. With additional incident identification and classification, future work could build on this initial report to provide deeper insights on root causes and effectiveness of preventative measures.

EPRI continues to conduct research in BESS safety, and the current portfolio[23] includes projects on thermal runaway off-gas characterization, propagation mitigation technologies, characterizing risks of siting BESS near critical infrastructure, first responder training, and more. These activities are done in collaboration with a variety of industry stakeholders including electric power companies, OEMs, fire departments, and other research organizations. Ongoing regulatory development, voluntary industry efforts, and focused research initiatives will continue to support increased BESS safety.

CONCLUSION

Industry efforts to improve BESS safety during a period of rapid deployment expansion have led to a sharp decrease in the failure rate, but areas of needed improvement remain. This analysis demonstrated that all stages of the product lifecycle contribute significantly to BESS safety and must be rigorously engineered and diligently tested. Notably, the data challenges the widespread assumption that the lithium ion battery cell is the primary cause of failure. The BOS and controls were the leading causes of failure, with the cell having a relatively small number of failures attributed to it. Finally, this analysis is limited by the data that is publicly available. Of the known incidents, less than a third were assigned a cause of failure due to lack of sufficient information. Industry transparency on details of BESS failures will be essential to more comprehensive analysis, to ongoing safety research, and to future development that will ensure the continued safe operation of BESS facilities.

23 *Battery Energy Storage Fire Prevention and Mitigation Phase III*. EPRI, Palo Alto, CA: 2023. 3002028531.

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- **TWAICE:** Ryan Franks, Sebastian Becker, Jordi Mueller
- **PNNL:** Matthew Paiss

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Founded in 1972, EPRI is the world's preeminent independent, non-profit energy research and development organization, with offices around the world. EPRI's trusted experts collaborate with more than 450 companies in 45 countries, driving innovation to ensure the public has clean, safe, reliable, affordable, and equitable access to electricity across the globe. Together, we are shaping the future of energy.

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Exhibit 5

UTILITY DIVE

DIVE BRIEF

More than a quarter of energy storage systems have fire detection and suppression defects: report

Defects such as faulty smoke and temperature sensors may be more common than some expect, according to clean energy advisory firm Clean Energy Associates.

Published Feb. 13, 2024 • Updated Feb. 23, 2024

By Emma Penrod

Battery energy storage projects face more defects and other problems than the power sector may expect, leading to potential performance and safety risks, according to Clean Energy Associates, a clean energy advisory firm.
PhonlamaiPhoto via Getty Images

Dive Brief:

- Battery energy storage systems may contain more defects and deviate from industry best practices more often than expected, according to six years of factory quality audits by industry advisory firm Clean Energy Associates.
- More than a quarter of inspected energy storage systems, totaling more than 30 GWh, had issues related to fire detection and suppression, such as faulty smoke and temperature sensors, according to the report.
- While the industry has generally focused on cell integrity, system level issues accounted for nearly half of the defects identified by Clean Energy Associates.

Dive Insight:

A significant percentage of the world's energy storage systems could contain defects that pose a risk of thermal runaway and fire, according to data released last week by Clean Energy Associates.

The advisory firm has compiled factory quality audit data on 64% of tier one lithium-ion battery energy storage system manufacturers over the past six years, identifying more than 1,300 manufacturing defects in the process. They found that 26% of energy storage systems contained fire suppression system defects, while 18% had defects in thermal management systems. Tier one systems are considered suitable for use in EVs manufactured outside of China, according to Benchmark Mineral Intelligence.

Faulty actuators that did not respond to the command to release a fire extinguishing agent were a relatively common finding in the Clean Energy Associates audits. The auditors also commonly encountered incorrect wiring in smoke sensors and temperature sensors, and often found fire alarm abort buttons unresponsive. Failure to deactivate a false alarm could lead to unnecessary releases of fire extinguishing agent or unwanted sprinkler system activation, which could cause serious damage to energy storage equipment, according to Clean Energy Associates.

More than half of the issues identified by Clean Energy Associates were system-level defects related to improper system integration procedures, according to the report. These defects include issues such as improper wiring and coolant leaks due to defective valves and loose pipe connections.

However, defects in the battery cells themselves accounted for just under a third of the issues identified by Clean Energy Associates. Cell-level defects typically pose greater risk to energy storage system performance and safety than system-level issues, according to Clean Energy Associates. Common problems include lack of calibration and welding defects, as well as electrolyte leakage, according to the report.

A final 23% of issues identified were related to battery module assembly, according to the report. Most module-level defects could be attributed to manual production lines, according to Clean Energy Associates.

The American Clean Power Association said the report should not be taken to suggest that these defects are prevalent in large numbers in installed energy storage systems already connected to the grid. Existing industry practices mean installers screen for and correct the deficiencies observed by Clean Energy Associates prior to system installation, according to Noah Roberts, senior director of energy storage for the association.

“Under current industry standard practices, and the nationally recommended safety standard, NFPA 855, all of the faults identified in this report would be corrected during the project installation and commissioning process,” Roberts said in a statement. “As we have seen over the past few years, the leadership of the energy storage industry and its prioritization of safety and reliability has made fire incidents in the field increasingly rare.”

Editor’s Note: This story has been updated with comments from the American Clean Power Association.

Exhibit 6

Many of California's Most Destructive Fires Were Caused by Power Lines

By Jeremy White Jan. 13, 2025

Investigators are still working to identify what caused the spate of fires that ignited around Los Angeles last week, but residents are concerned that electrical infrastructure may have sparked at least one of them.

Since 1992, more than 3,600 wildfires in California have been related to power generation, transmission and distribution, according to data from the U.S. Forest Service. Some of the most destructive fires have been traced back to problems with utility poles and power lines.

Extent of power line fires near Los Angeles

Roughly a dozen power line fires have burned more than 200,000 acres in areas northwest of the city since 1970.

Cumulative extent of previous fires known to be caused by power lines

Source: CalFire • Extents of recent fires, as of Jan. 13, are outlined in black. • By The New York Times

CalFire releases data on past large wildfires and determines their causes in different natural and human-related categories, such as lightning or arson. The agency lists more than 12,500 fires since the late 1800s, though the causes of more than half are unknown or unidentified.

Lightning and use of equipment are among the most common known causes, but over the past few decades, the share of fires known to be caused by power infrastructure has grown across the state.

The 20 most destructive California wildfires

At least eight of California's most destructive wildfires had either electrical or power line causes. Those fires are shown in **bold**.

YEAR	NAME	STRUCTURES DESTROYED
2018	**Camp**	**18,804**
2017	**Tubbs**	**5,636**
2025	Palisades (under investigation)	5,316
2025	Eaton (under investigation)	>5,000
1991	Tunnel	2,900
2003	Cedar	2,820
2020	North Complex	2,352
2015	**Valley**	**1,955**
2007	**Witch**	**1,650**
2018	**Woolsey**	**1,643**
2018	Carr	1,614
2020	Glass	1,520
2020	LNU Lightning Complex	1,491
2020	CZU Lightning Complex	1,490
2017	**Nuns**	**1,355**
2021	**Dixie**	**1,311**
2017	**Thomas**	**1,063**
2021	Caldor	1,003
2003	Old	1,003
1999	Jones	954

Source: CalFire • By The New York Times

Residents of Altadena, Calif., sued Southern California Edison on Monday, saying the utility's electrical equipment set off the Eaton fire, which has burned more than 13,000 acres and 5,000 structures in the city and neighboring areas. The company has said it is investigating the fire's origin.

Power distribution lines were found to have caused some of California's largest-ever fires in recent years.

The Thomas fire in 2017 was started when high winds forced Southern California Edison's power lines to collide, a situation known as "line slap." Burning material fell to the ground in the Upper Anlauf Canyon, about 35 miles from the current Palisades fire, and the resulting fire burned for almost 40 days.

The 2018 Camp fire, in Northern California, started when an electrical arc between one of Pacific Gas & Electric's power lines and a steel tower sent molten metal onto the underlying vegetation. That fire claimed more than 80 lives and destroyed over 18,000 structures.

In the summer of 2021, California's largest single-source wildfire, the Dixie fire, started when a tree made contact with several of PG&E's distribution lines near the Cresta Dam in Northern California. Electricity continued flowing in one of the lines, which started the fire, and nearly a million acres across four counties burned.

California isn't the only state dealing with power-related wildfires in recent years. Texas' largest wildfire, the Smokehouse Creek fire, burned over a million acres in 2024. Xcel Energy accepted responsibility for the fire after investigators found that high winds had broken a utility pole, causing a power line to fall and ignite the dried grasses below.

Similar situations have caused wildfires in Oregon as well. The 2020 Labor Day fires destroyed thousands of homes and killed at least nine people, in part, after power wasn't shut down during high winds.

Exhibit 7

Fire and Solar PV Systems – Investigations and Evidence

Prepared for: **Malwina Gradecka and Yehuda Lethbridge, SICE, BEIS**

Date: 11th May 2018

Report Number: **P100874-1004** Issue 2.9

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Date 11th May 2018

Contract and use

This work has been carried out by members of the Building Research Establishment Ltd (BRE), BRE National Solar Centre (NSC) and the BRE Global Fire Safety Group, on behalf of the Department of Energy and Climate Change, Contract number TRN 1011/04/2015, agreed, 21/07/15. Since July 2016, the Department of Energy and Climate Change has been merged with the Department for Business Innovation and Skills to create a new Department for Business, Energy and Industrial Strategy (BEIS).

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Contents

1 Introduction

1.1 Background

Over the past few years, there have been a number of media reports linking photovoltaic power systems (PV) with fire. With nearly 940,000 PV systems now installed in the UK, an increase in incident reports is to be expected.

The National Statistics website[1] shows that, as of the end of December 2017, overall UK solar PV capacity stood at approximately 12.75 GW. Figure 1 shows the scale of the increase in deployment since 2010, when the feed-in tariff (FIT) was first introduced.

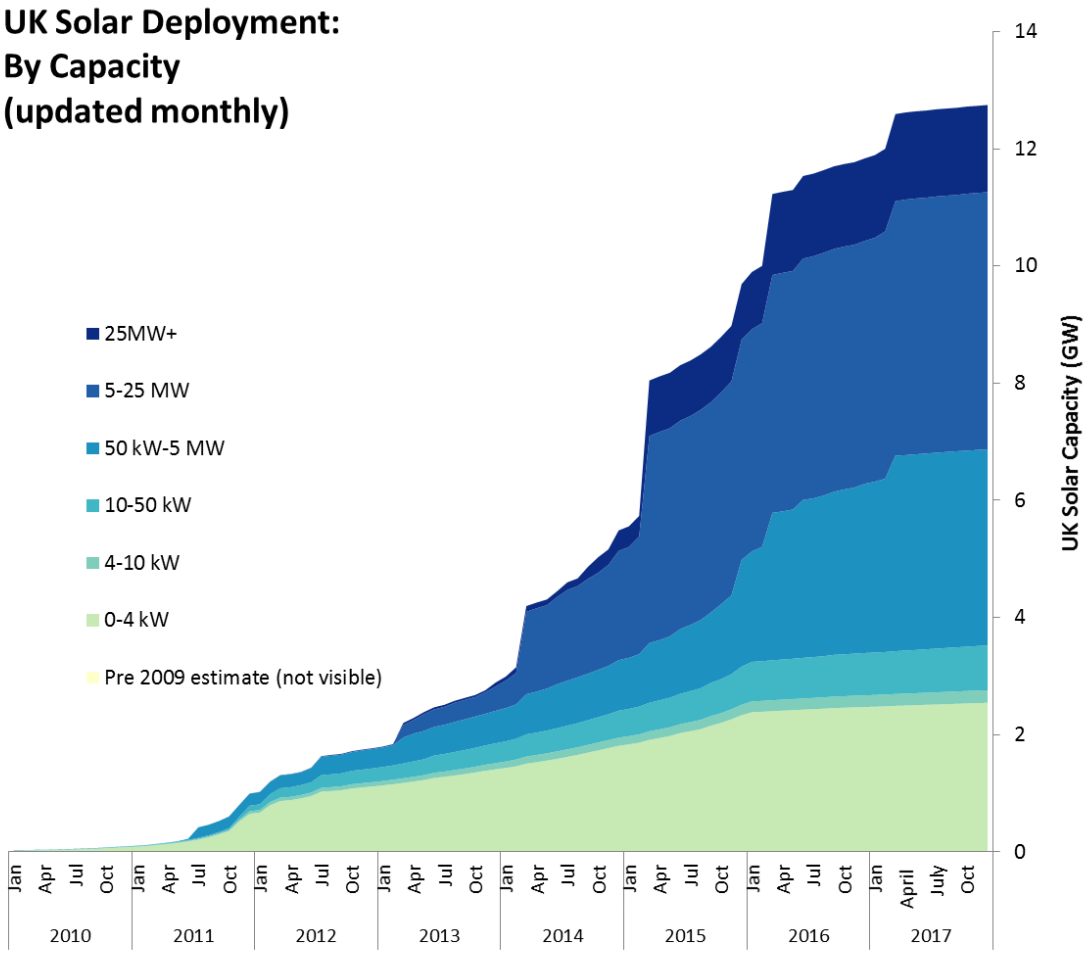

Figure 1: UK PV deployment to December 2017[1]

[1] www.gov.uk/government/statistics/solar-photovoltaics-deployment

At this point in time (December 2017), 46% (5,893 MW) of total installed UK solar PV capacity came from large scale installations greater than 5 MW, with 20% (2,531 MW) coming from small scale 0 to 4 kW installations, and the overall UK solar PV capacity stood at 12,748 MW across 937,421 installations (provisional figure). This is an increase of 32% (3,057 MW) compared to December 2015.

Prior to this project there was little information available with regards to PV related fire incidents. Statistics relating to fire incidents attended by Fire and Rescue Services (FRS) are published by the Government[2], however, the data is high level and it is not possible to identify which incidents may have involved a solar PV system. Typically PV related fires have been reported by the press[3], other incidents have become known through word of mouth[4], and it seems likely that a larger number of fire incidents have not been reported to FRS or through consumer protection channels (such as the Microgeneration Certification Scheme and Renewable Energy Consumer Code), especially where installers have been able to contain and rectify the fault without intervention from the FRS.

Previously, there appears to have been no detailed follow-up investigation in order to properly understand the causes of these fires, or how the presence of PV on a building may have influenced firefighting operations.

The main causes for ignition of PV related fires are not seen as common hazards in traditional AC electrical systems. This is partly because the electrical industry standards, practices and component designs have evolved over the last 100 years or so to a point where most modern installations are very safe. Despite the now significant number of PV systems installed in the UK and elsewhere PV standards, practices and components, however, are relatively young by comparison and are still evolving[5].

The acquisition of incident data from the field, analysis of root causes and reporting is therefore vital to ensure that standards committees have the latest information to work with, creating the conditions for standards to remain relevant and effective. Safety is overarching and it should be the industry's ambition to minimise risk in PV systems.

Also, how PV systems can influence firefighting operations may be an essential input during the ongoing development of standards. Standards provide information on safety consideration, however, at present there is a lack of coverage of fire safety issues, including firefighting response.

This project has therefore been established in order to collate accurate information - both historical (pre-project start) and contemporary (reported to BRE since July 2015 for this project) – on fire incidents involving PV systems, and on relevant previous research. The aim of the project is to feed

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[2] https://www.gov.uk/government/collections/fire-statistics

[3] http://www.bbc.co.uk/news/uk-england-sussex-32382795, http://www.telegraph.co.uk/news/2017/07/02/fire-sweeps-new-block-london-flats-witness-claims-started-solar/

[4] Following conversations with members of the Solar Trade Association

[5] There are currently 67 published British Standards relating to PV technologies, 19 of which were published in 2017.

the data and conclusions into industry standards (e.g. [1], [2]) and the National Occupational Guidance system [3], which is used to disseminate information to the fire and rescue services.

The project team has completed the following work:

- a literature review
- a review of standards
- a review of available PV installer training and PV training for firefighters
- a database of PV fire incidents
- a series of on-site investigations and desk studies of contemporary incidents
- disseminated the findings and recommendations of the research to the fire sector, including presenting at BRE's Fire Research Conference and the UK Association of Fire Investigators Annual Training Conference
- disseminated the findings and recommendations of the research to the relevant national and international standards committees, including BSi, IEC and MCS
- disseminated the findings and recommendations of the research to the UK solar industry through a PV Fire Workshop
- disseminated the findings and recommendations of the research to solar installation training providers through a Train the Trainer event

The public project description can be found on BRE National Solar Centre's website: http://www.bre.co.uk/nsc/page.jsp?id=3676.

2 Project outline

The project began in July 2015 and finished February 2018. This report is the final output from work package (WP) 4. A short outline of the project is presented below.

2.1 Organisations involved

The project team comprises the following organisations and individuals:

- BRE National Solar Centre (NSC)
- BRE Global Fire Investigation Group
- Fire Investigations (UK) LLP (FI-UK)
- A representative of the Chief Fire Officer's Association (CFOA)
- A representative of Prometheus Forensic Services Ltd
- Individual PV experts

The project is funded by the Department for Business, Energy and Industrial Strategy (BEIS).

2.2 Programme

Table 1 gives a brief description of the complete three year project, formed from the following work packages:

WP	Description	Status
1	Review of relevant literature. The literature review produced a total of 184 references, mainly from the PV industry, academia and fire services. The full report was submitted to BEIS 25/11/15.	Completed November 2015, minor modifications March 2017
2	Surveys of standards and training. Standards were mainly international (e.g. IEC), whilst training courses were mainly domestic. The full report was submitted to BEIS 25/11/15 and incorporated into the literature review report.	Completed November 2015
3	Survey of historical incidents in the UK – the survey involved contacting installers, building owners, the fire services and DCLGs Incident Reporting System. 37 unique historical incidents of fire involving PV systems in the UK were identified. The output was reported as part of WP5.	Completed January 2016
4a	Investigations of live and recent PV fire incidents in the UK. WPs 1 – 3 and 5 laid the foundations for on-going investigations into incidents, as they arise (WP4).	Completed February 2018
4b	Additional Work Package introduced as a variation to the contract to enable laboratory examinations of components suspected of causing fires on PV systems to be undertaken. The data from these examinations feed into WP4 and are stored within the database.	Completed February 2018
5	Database development and initial population with historical records.	Completed December 2015
6	Fire and Solar PV Systems – *Literature Review, Including Standards and Training** derived from WP1 & 2).	Completed March 2017
7	Fire and Solar PV Systems – *Investigations and Evidence** (derived from WP3, 4 & 5).	Completed March 2017, updated February 2018
8	Fire and Solar PV Systems – *Recommendations*:* a) *for PV Industry* (derived from WP6 & 7). This report. b) *for the Fire and Rescue Services* (derived from WP7 & 8)	Completed March 2017
9	Dissemination to BEIS and the solar and fire safety industries	Completed February 2018

Table 1: Project work packages and status*

***** Note: Following a meeting with BEIS in November 2016, the outputs from work packages 6, 7 and 8 have been recast, as shown in the table. The original work packages were as follows:

WP6: Recommendations for improving design and maintenance standards

WP7: Recommendations for improving training

WP8: Recommendations for the safety of fire-fighters in the event of fires involving PV

2.3 Reports

The following reports form the published output from the project. The Investigation and Evidence report (this report) has been revised from the interim report published by BEIS in July 2017[8].

- A review of relevant literature, standards and training [4]
- Fire and Solar PV Systems – *Investigations and Evidence* - this report
- Recommendations for the PV industry [5]
- Recommendations for Fire and Rescue Services [6]

3 Methodology

3.1 Review of literature, standards and training

The starting point for the project was a review of relevant literature (WP1). The literature review produced a total of 184 references, mainly from the PV industry, academia and fire services. Next, two further reviews were conducted on relevant standards and training courses.

These reviews are presented as a separate document: Fire and Solar PV Systems – *Literature Review, Including Standards and Training* [4].

3.2 Communications

Under WP3, members of the team used contacts in the fire and PV sectors to seek historical information on known fire incidents involving PV systems. The information gathered was then fed into a database, developed by the project team (described below).

Communications via the Chief Fire Officers Association (CFOA) and the Microgeneration Certification Scheme (MCS) allowed relevant organisations and individuals to be informed of the live incident investigation capability of the project (WP4) and request that any incidents involving PV systems be reported to the team in real time, or as soon as possible after the event.

A project description was also set up on the NSC website: http://www.bre.co.uk/nsc/page.jsp?id=3676 and an approved article was published in Renewable Energy Installer magazine in December 2016. All communications carried contact details specifically set up for the project:

email: solarfire@bre.co.uk and a telephone number: 0333 0033 314.

As a result of the communications efforts, as well as regular media searches, data on live or recent incidents started to arrive. In cases where remedial measures had been completed, or evidence destroyed, the team opted not to visit the site, but to collect data by telephone and email (‘desk studies’).

3.3 Establishment of the database

In order to provide a secure and durable location to store data on fire incidents collected during the life of the project, a basic database with a secure web portal interface was designed, tested and implemented on a server located at BRE headquarters in Watford (WP5).

The information to be captured by the database was selected by discussion with BEIS (then DECC) and fire and PV experts at BRE.

The information necessarily contains personal data (names and addresses) and commercially sensitive data (names of products, suppliers, etc.). This is to ensure validation of information sources and to prevent duplication of incident records. Therefore, in accordance with the contract with BEIS and BRE’s own procedures, the data resides only on the secure server at BRE, with only named members of the BRE team having controlled access. The database has the facility to export anonymised records only.

The diagram in Figure 2 illustrates the flow of incident data and the conceptual structure of the database.

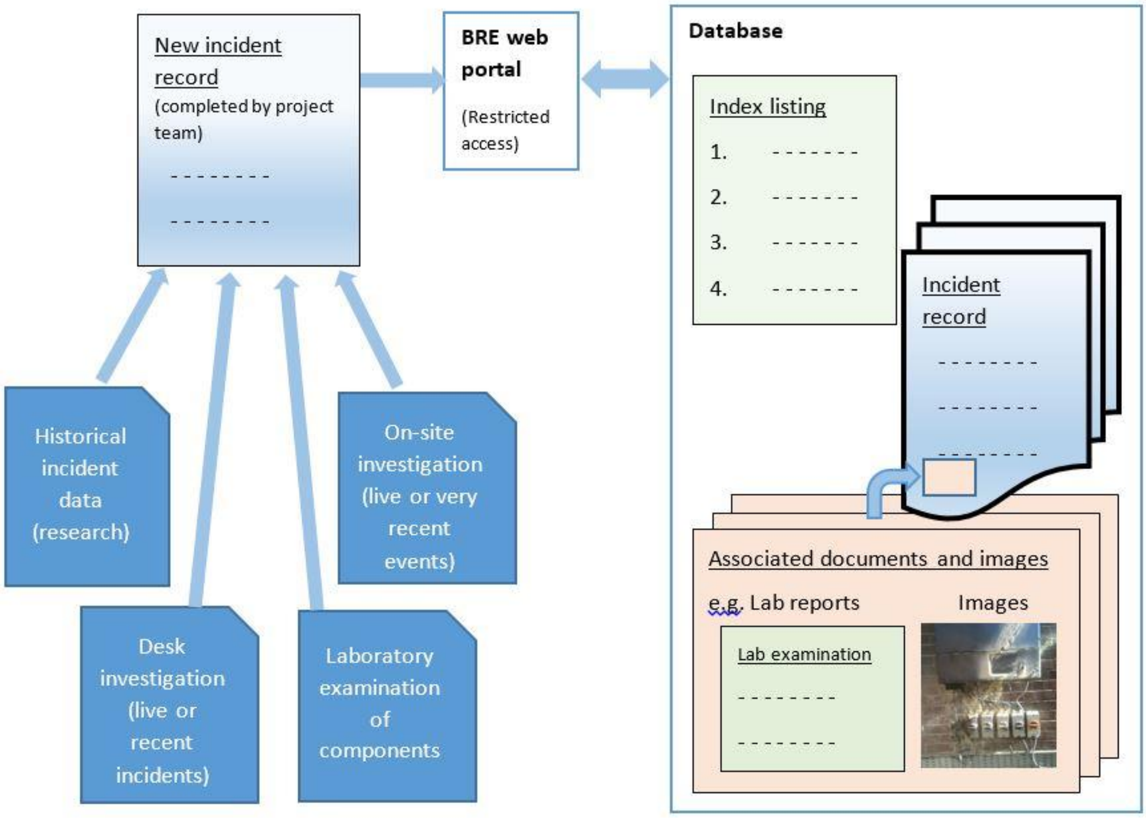


Figure 2: Fire incident data flow and conceptual structure of database. Each record consists of some 75 data fields.

A more detailed description of the database data fields and images of the interface portal can be seen in Appendix A. An anonymised summary of the records to date is provided in Appendix B.

There are currently a total of 80 unique records of fire incidents involving PV in the database. These are made up of 33 historical incidents and 47 that have been investigated by the team, either on-site or by desk studies.

3.4 Incident investigations

Once the database and portal had been set up and tested, the historical incident data collected under WP3 were entered. Data from new incidents were entered as the information became available from on-site, laboratory and desk investigations. Each incident is assigned a unique identification label, of the form “PVFxxxx”, where “xxxx” is a serial number. The various data collection activities are described below.

It should be noted that data on “thermal events”, incidents in which overheating occurred, but did not develop into a fire, were also captured where possible. These incidents are interesting because they can provide direct evidence of potential causes of fires, with only the overheated components being affected and the area around them being undamaged. Usually, thermal events are noticed when smoke is seen to be issuing from a component.

3.4.1 Historical incident research

The historical incident data was gathered mainly by networking with PV industry contacts and fire services, as well as internet searches.

Under WP3, members of the team used contacts in the fire and PV sectors to gather information on known historical fires involving PV systems (see details in 3.2, above). The DCLG Incident Reporting System (IRS) used by the fire services to record fires was also interrogated. However, the IRS records tend to contain little technical detail on PV-related incidents. Some members of the team were already aware of some incidents and this information was also used where possible.

A data capture form was developed to reflect the database fields, so as to record the data as consistently and completely as possible. The content of the form is virtually identical to that shown in Appendix A, User interface.

The resulting data from the above exercise were then filtered for duplications, as several reports were found to refer to incident data already captured, but with a slightly different name or description.

Data was collected on a total of 33 historical incidents: PVF0002 – PVF004, PVF0006 – PVF0028, PVF0030 – PVF0034, PVF0036 and PVF0038. (The incident numbers are not continuous because data from some earlier investigations, commissioned outside of the project, have been included, and also there was a brief period when live and historical data was arriving simultaneously).

3.4.2 Site investigations

An important feature of the project is the active, fast response, on-site forensic investigations conducted whenever the team was made aware of a suitable incident. The criteria for whether or not to send a team to site is detailed below.

There are three potential scenarios in deciding whether or not to send an investigation team to the site:

a) Any incident where a PV system is **clearly implicated** as a possible cause of the fire, or a significant hazard for fire fighters. The team would normally seek access to the site in order to investigate. This is not always straightforward as the Fire & Rescue Service (FRS) will not give out any contact details of building owners, so we are often reliant on the FRS to pass our details to the site owner.

b) Where a PV system is present, but **clearly not implicated** as a cause (e.g. common kitchen fire, such as that from a deep fat fryer). We enquire with the FRS to determine if the PV system caused any concerns or created extra hazards during the firefighting activities. If there were any such issues, these would be recorded, but we would not generally visit the site.

c) Where a PV system is present, but it is **unclear whether it is implicated** as a possible cause of a fire, we will interview the relevant FRS and, based on the information received, make a decision on whether the site should be visited. In general, if a part, or parts, of the PV system appear to have been damaged, we will send a team to investigate. Where the PV system appears to be undamaged and the FRS reports no issues relating to the PV system we will not investigate further.

In general, a fast response is required so that evidence can be viewed on site prior to any further disturbance from restoration works. The team was normally able to mobilise within 24 hours if permission to access the site had been obtained.

3.4.2.1 Interactions with insurance investigators

It is important to understand that there are other parties with an interest in building fires, aside from the owner and the FRS. Generally, insurance companies will commission their own investigation into the causes of a fire, via a loss adjuster and specialist investigator.

Part of the team's process when attempting to gain access to a site is to establish and make contact with the relevant insurer, loss adjuster or investigator if possible, so as to explain the purpose of the project and give confidence that the team will not disturb evidence likely to be of interest to the insurer's investigator. Usually, if this communication is handled appropriately, the other parties are happy to have the site investigation team on site and will generally agree a time when all parties can be present and can exchange observations and thoughts. This arrangement can be of mutual benefit, allowing more pairs of expert eyes and PV and forensic knowledge to be applied to the investigation at the scene of the fire.

3.4.2.2 Site investigation team

The site investigation team is composed of PV experts and forensic fire investigators. Wherever possible, a PV expert and a fire investigator coordinate to visit the site at the same time. The site investigators underwent training in an early stage of the project in August 2015 and February 2017. The PV experts trained the site investigators and vice versa, with the major focus on health and safety aspects of such site visits.

The site investigation team consisted of 7 professional fire investigators and 6 PV experts. The fire investigators are drawn from FI-UK, the PV experts are from the BRE NSC, BRE Scotland, BRE Wales and one independent consultant.

3.4.2.3 Health, safety and communications on site

Damaged PV systems can be dangerous, so the first priority at fire scenes is health and safety. In each case a risk assessment (RA) is undertaken at BRE prior to the site visit, using available information. Upon arrival on site, the RA is updated with a dynamic assessment of the potential hazards. Typical risks to be assessed and controlled are as follows:

- Falls
- Trips & slips
- Electrocution
- Burns
- Collisions with objects (e.g. banging head on scaffold)

The building is only entered once the hazards have been assessed and controlled sufficiently (e.g. assessing and avoiding dangerous areas, wearing suitable PPE, etc.) to reduce the risk to an acceptable level. Risk assessments have been stored on a server located at BRE headquarters in Watford.

At non-domestic sites, a briefing is sought in order to comply with site regulations, obtain contacts and for orientation.

Good communication with all parties is essential to ensure access to the site, avoid misunderstandings and avoid causing any extra stress to building owners. Therefore, building owners or operators, FRS, insurance investigators, trade, installers, safety officers, site services, etc. must be consulted, as appropriate at each scene. In general, once the research project has been explained, our experience is that most people are supportive and helpful.

3.4.2.4 Physical inspection

The same data capture form that has been used for historical incident research has also been used on site investigations to capture the details of new incidents. All information has been collated in the database.

After the health and safety processes have been completed, the visit normally continues with a short survey of the whole PV system (if possible) and the areas affected by the fire. If the building owner/operator or any witnesses are on hand and they are happy to share information, a conversation is initiated to help piece together the sequence of events leading to the fire incident.

If the relevant parts of the building are deemed stable (this is usually the subject of discussion with FRS operatives/investigators and fire investigators) a detailed search of the apparent seat of the fire, as determined by burn patterns and witness reports, then ensues. This can involve sifting through debris in great detail to look for clues.

Figure 3 shows an example of a domestic roof, with a PV system fitted, destroyed by fire.

Figure 3: Example burnt-out roof with parts of the PV system intact.

Some examples of evidence and its interpretation are shown in section 4.

To date, there have been a total of 21 on-site investigations (incident references PVF0001, PVF0005, PVF0039, PVF0041, PVF0051-58, PVF0060, PVF0062, PVF0065-67, PVF0071-72 and PVF0075-76) in

- 10 dwellings,
- 4 commercial buildings,
- 2 residential homes,
- 2 leisure centres,
- 1 school,
- 1 industrial building and
- 1 ground-mounted system.

The sequence of reference numbers shows an increase in frequency of site visits over project duration, as occurrences of PV fires tend to increase in early spring, when the first very sunny days of the year occur, and tail off in late autumn. The project commenced in winter 2015, with more frequent incident in months leading up to the summers of 2016 and 2017.

3.4.3 Laboratory examinations

In cases where a component is identified as the likely cause of a fire incident, the remains may be removed from the scene (with the owner's permission) and transported to a laboratory at BRE for further forensic inspection. A typical example would be a DC isolator switch (see Figure 4), which requires disassembly in a controlled environment and close inspection of small parts in order to arrive at conclusions on the probable cause.

Figure 4: Remains of a DC isolator being disassembled and inspected in the laboratory
(Photo courtesy of Fire Investigations (UK) LLP)

The bench examinations were performed by staff from FI-UK, in their dedicated laboratories at BRE.

A typical examination involves the careful and methodical disassembly of the part under scrutiny, whilst recording any observations. The operative then uses their fire investigation experience to weigh the evidence and arrive at a conclusion on the likely cause of the damage, if possible.

In total, 7 laboratory examinations of components removed from sites have taken place: (incident references PVF0005, PVF0035, PVF0039, PVF0041, PVF0047, PVF0053 and PVF0058).

An example laboratory examination report (redacted) can be seen in Appendix C.

3.4.4 Desk investigations

On the occasions when the project team has been made aware of an incident sometime after the event, or has been unable to gain prompt site access (i.e. longer than 5-10 days), it is likely that there is less value in completing an onsite investigation, due to onsite activities disturbing, or the removal of, potential evidence. In these cases a desktop study has been completed. This research approach is limited to interviews by telephone and other desk-based activities. If useful data is acquired, it is entered directly into the database.

To date, 26 desk-based investigations have taken place: incidents: PVF0035, PVF0037, PVF0040, PVF0042-50, PVF0059, PVF0061, PVF0063-64, PVF0068-70, PVF0073-74, and PVF0077-81.

4 Mechanisms for ignition of fires on PV systems

4.1 Introduction

This research has investigated 80 potential PV related fire incidents, representing approximately 0.01% of the current number of installations installed in the UK.

Fire incidents can have a marked impact on people and property. For PV fires, where little detailed information currently exists, it is important to understand the likely mechanisms of ignition in PV systems.

4.2 Electrical Arcing

Electrical arcing is the flow of electrical energy through an air gap by way of ionised gas molecules. Whilst air is normally regarded as a non-conducting medium, a high potential difference (voltage) between two conductors in close proximity can cause the air molecules to break down into their ionised constituents (called a 'plasma'), which can then carry a charge from one electrode to the other.

The temperature of an electrical arc depends on a number of factors, such as the level of current flow, but on a typical PV system, it is easily hot enough to melt glass, copper and aluminium, and to initiate the combustion of surrounding materials.

Arcing is not seen as a common hazard in traditional AC electrical systems due to established electrical industry standards, practices, component designs and experienced workforce.

Another reason that arcing is less of an issue in AC systems is that arcs tend to self-extinguish as the voltage alternates, passing through 0 volts 100 times per second for standard grid supplies. This means that for an arc to be self-sustaining, the conditions for starting the arc have to be present continuously. DC, on the other hand, remains at a continuous voltage and, once an arc has been established, tends to support its continuation.

Thus any evidence of arcing found on sites, whilst not conclusive, points towards a possible, even probable, cause of the fire.

4.3 Evidence of arcing

Figure 5 shows a photograph of evidence of a typical arcing event affecting a DC connector, alongside a similar component that was in the same area of the fire, but without arc damage.

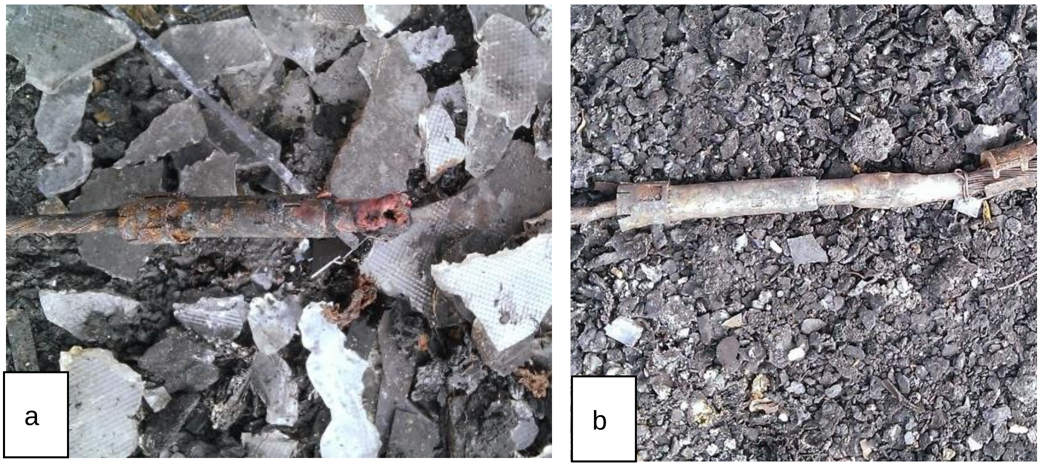


Figure 5: Remains of a DC connector ablated by arcing (a), and by contrast, a connector with contacts still intact and engaged, merely damaged by the surrounding fire (b). In both cases, the insulating body of the connector has been burnt off.

4.4 Causes of arcing

Other sources of heat, such as resistive heating in a corroded connection, could also be an ignition point for a fire, but the temperatures involved tend to be much lower than for an arc. However, such heating can still be a precursor to establishing an arc. For example, it is known that electrical contacts that are exposed to water and oxygen are likely to corrode. It is also known that the build-up of oxide layers on the contacts can lead to resistive heating which, over a period of time, is likely to cause the breakdown of surrounding materials. Once this has occurred, the loss of mechanical integrity of the component can then lead to a break in the circuit and, if conditions allow, the establishment of an arc.

Another potential cause of arcing is the existence of a simple poor connection. Thus the likely causes of arcing on a PV system may be summed up as follows:

- Moisture ingress degrading connections in connectors, junction boxes and switches
- Incorrectly crimped connector contacts
- The mating of incompatible plugs and sockets
- Plugs and sockets not fully engaged
- Loose screw terminals within junction boxes or isolator switches
- Poorly soldered joints within a PV module junction box or other junction box defect
- Damage to a component (e.g. broken busbar within a PV module).

4.5 Other potential mechanisms

Aside from arcing, resistive heating (alone) can be the cause of fires. However, the energy involved tends to be self-limiting: the higher resistance reduces the current in the circuit, which reduces the heating effect disproportionately (Heat = Current^2 x Resistance). Therefore, it is far less likely than arcing to be the only causative mechanism, but as mentioned above, can be a precursor to arcing.

Breakdown of electronic components, such as capacitors or transformers, is possible and these are thought to be likely causes of fires in inverters. However, the statistics collected do not highlight inverters as a common origin of fires.

4.6 Spread of fire

For some of the incidents investigated it was clear to see how the fire had spread from an arc or single component to other areas of the PV system and/or building. Although spread of fire was not included as a specific point to include in this research, there is anecdotal evidence which highlights the increase risk of spread of fire for components installed in loft spaces, where the roof timbers and stored items can provide an additional fire load.

One specific incident also demonstrated the spread of fire along an ‘in-roof’ mounting system, where the PV modules replace the roofing fabric.

5 Findings

5.1 Overview

A total of 80 incidents have been investigated and incorporated into the database.

The information resulting from the research on historical incidents is less complete than that gathered during active investigations, mainly because previously such incidents have not been logged in any central information store and varying levels of detail are recoverable. However, the completeness of information improves from record PVF0039 onwards as the later records are of investigations conducted by the project team (on-site, from desk or laboratory examinations).

A summarised, anonymised listing of the database records can be seen in Appendix B.

5.2 Data sources

- 33 are historical incidents[6], arising before the initiation of the project
- 21 of the recorded incidents were desk investigations
- 26 records are of on-site investigations
- 7 of the above records include laboratory examinations of components

5.3 Fire severity and PV involvement

Table 2 shows a breakdown of the types of fire by severity and the relative involvement of the PV system.

Severity of fires	PV involvement			
	Caused by PV	Involving PV but not caused by	Cause unknown	*Total*
Serious fires	22	15	1	*38*
Localised fires	27	1	5	*33*
Thermal events	9	0	0	*9*
Total	*58*	*16*	*6*	***80***

Table 2: Summary of severity of fire and PV involvement

The severity of fires (historical and contemporary) have been classified by the researching/ responding BRE fire investigator, using the following reasoning:

- *Serious fires* were difficult to extinguish and spread beyond the area of origin.
- *Localised fires* caused some damage to areas surrounding the point of origin, mainly affect PV system components, but did not spread beyond that or threaten the building.

[6] Information provided by IRS, internet searches and interviews with UK solar industry and FRS.

- *Thermal events* consist of components that over-heated, often observed to be smouldering or producing smoke, but did not develop into a fire.

5.4 Casualties

Generally, PV fires have caused damage to PV installations themselves and sometimes to the buildings on which they are mounted. To date and in the incidents reviewed for this report, a total of 12 casualties have been reported. The analysed Fire and Rescue Services statistical data does not link the presence of PV systems to fatalities from fire originating from these PV systems. Table 3 shows the number of casualties recorded from all sources of information[7].

Injuries / fatalities	Fire caused by PV	Fire not caused by PV	Cause unknown	*Total*
Injuries / psychological trauma	9[8]	1[9]	0	*10*
Fatalities	0	3[10]	0	*3*
Total	*9*	*4*	*0*	***13***

Table 3: Numbers of casualties recorded in all incidents

The injury types are broken down as shown in Table 4:

Types of injury	Number of people
Smoke inhalation (treated at scene)	6[11]
Minor burn	1[12]
Shock and anxiety	1[13]
Minor injury to knee	1[12]

[7] The confidence levels in the numbers resulting from site visits and desk studies is high. Information from the historical incidents is less complete.

[8] Information obtained by BRE as follows: 5 onsite investigations, 1 desktop investigation, 3 historical incidents (from other sources)

[9] Information obtained by BRE from other sources

[10] Information obtained by BRE as follows: 2 from 1 onsite investigation, 1 historical incidents (from other sources)

[11] Information obtained by BRE as follows: 4 onsite investigations, 2 historical incidents (from other sources)

[12] Information obtained by BRE from onsite investigation

[13] Information obtained by BRE from other sources

Electric shock	1[14]
Fatality	3
Total	*13*

Table 4: Break down of injury types (all incidents)

5.5 Building or site type

There is an even split between domestic buildings and non-domestic buildings. The latter encompasses commercial as well as public buildings (e.g. schools).

Type of building / site	
Domestic buildings	37[15]
Non-domestic buildings	37[16]
Solar farms	6[17]
Total	*80*

Table 5: Type of building / site affected by fire

Generally, non-domestic buildings are easier to investigate. In these buildings, permission to access the site tend to be quicker to obtain, there may be a knowledgeable facilities operative and/or maintenance records. Many commercial buildings accessed had flat roofs, which are easier to, access and work from than damaged pitched roofs, typical in domestic properties.

Solar farms tend to have a tightly controlled maintenance agreement with an Operation and Maintenance (O&M) company. Anecdotal evidence indicates that many solar farm incidents have occurred that have not been reported to the project, or even to the local fire services in some instances. This is because the O&M companies, usually on rapid response service level agreements, tend to deal with issues as they arise and buildings and people are often not affected.

[14] Information obtained by BRE from desktop investigation

[15] Information obtained by BRE as follows: 10 onsite investigations, 10 desktop investigation, 17 historical incidents (from other sources)

[16] Information obtained by BRE as follows: 11 onsite investigations, 14 desktop investigation, 12 historical incidents (from other sources)

[17] Information obtained by BRE as follows: 2 desktop investigation, 4 historical incidents (from other sources)

5.6 PV components implicated

Of the incidents that are either known or likely to have been caused by the PV system, fires were recorded to have originated within particular components with the following frequency:

PV Components	Probable	Possible further	*Total*
DC isolators	26	2	*30*
DC connectors	5	7	*12*
DC cables	1	4	*5*
Inverters	6	3	*9*
PV modules	2	3	*5*
DC Combiner Box	1	0	*1*
Unidentified components	4	0	*4*
Total	*45*	*19*	

Table 6: Frequency with which PV components were recorded as the likely cause of fire

All of the samples examined in the laboratory were DC isolators (in just one of these cases the source of the fire was attributed to a connector adjoining the isolator, rather than to the isolator itself). A description of how the above statistics were obtained from the evidence is given in section 5.7, below.

5.7 Root cause

Our analysis suggests there are three possible root causes for PV fires:

- an error in the system design,
- a faulty product (design or quality issue) or
- poor installation practice.

Whilst in some cases it has been possible to identify the root cause, it is not always possible to discern which of these caused a particular incident. However, the best interpretation we have from the information in the database is as follows:

Root cause	Probable	Possible further
System design issue	6	3
Faulty product	3	10
Poor installation	21	2
Unknown	28	0
N/A (fire not caused by PV)	22	0
Total	*80*	

These figures should be treated with caution until there is more data available.

6 Interpretation of scene evidence

In this report, for the sake of brevity, we do not attempt to describe how every factor and piece of evidence noted at each site or in each witness statement contributed to the interpretation of the data for each incident. However, the examples below illustrate typical evidence for the most common causes of fire attributed to PV systems.

It is suspected that where a non-specialist (e.g. building owner, site manager or FRS) has supplied the information, the terminology may not be as precise as would be used by a PV specialist. For example, ‘connectors’ may be referred to as ‘cables’. Therefore, it is important to understand that there are inevitably uncertainties in the data caused by the variable level of PV expertise on the part of the person reporting. Where the project team has investigated on-site, this is not an issue.

6.1 DC Isolators

DC isolators were found to present the greatest fire risk within the database of incidents. Approximately 30% of the incidents recorded in this study were caused by malfunctions within this component. Often, the evidence is clear, especially where the fire is localised. An example is shown in Figure 6.

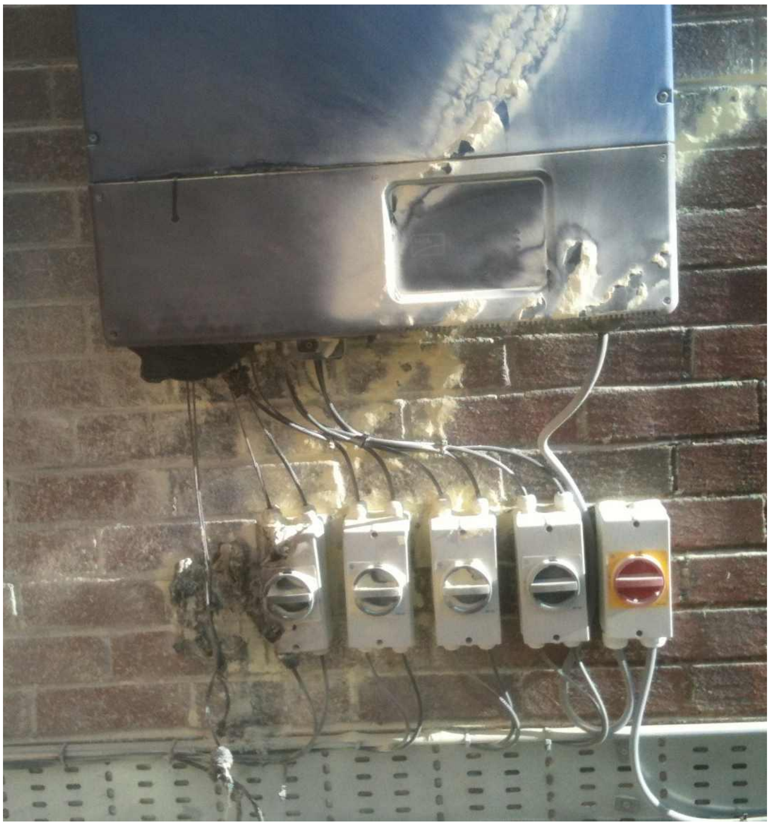


Figure 6: Localised fire in which the left hand DC isolator is completely missing, destroyed by a fire, with collateral damage to the adjacent isolator and inverter above.

In this case the evidence from the site and also the laboratory report (included in Appendix C) indicated that the isolators, which were mounted on an exposed exterior wall, were filling with water via the top-mounted cable entries. Across all the incidents reviewed, 7 incidents involved ingress of water into DC isolators, all with upward-facing cable glands.

There is also evidence of fires originating within DC isolators with poor contact design (originally being designed for AC operation and being re-designated as DC-rated by the manufacturer) and with incorrect internal wiring. An example with both of these issues is shown in Appendix D.

In 2014, prior to the start of the PV fire project, evidence of such issues submitted to BRE prompted the publication of a report on the correct selection and deployment of DC isolators on PV systems [7].

Interpreting the data, there appear to be three separate issues with DC isolators:

1) Poorly designed or constructed products - The contact design is particularly important for DC isolators. Models that were originally designed for AC are unlikely to be reliable over the life of a PV system. There is 1 possible instance of this (PVF0047), but there was also a pertinent installer error in that case, so the evidence to date is anecdotal and not yet conclusive.

2) Incorrectly specified DC isolators – there were 2 instances of this type of fault (PVF0037 and PVF0049). In both cases, the isolators were under-rated for the current or voltage of the PV strings connected.

3) Poor installation practice - 9 instances of poorly installed DC isolators were identified. This category therefore accounts for the majority of DC isolator failures leading to fires or thermal events.

   In 7, possibly 8, cases of poor installation, the result of the error was the ingress of water into the isolator casing, subsequently causing arcing. In several cases, this was caused by multiple cables being passed through a sealing gland designed to hold one cable. This issue is most acute when the gland is mounted on the upper surface of an isolator enclosure that is exposed to weather – see Figure 7.

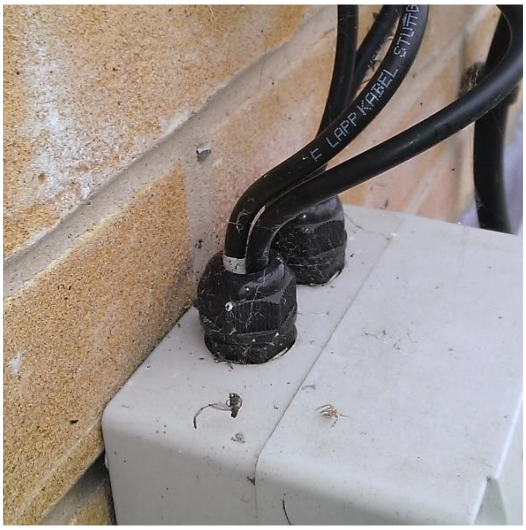


Figure 7: More than one cable passing through an upward-facing sealing gland on a DC isolator enclosure mounted on an outside wall.

Even where one cable of the correct size passes through an upward-facing, exposed gland, water may penetrate the enclosure – this was the case for at least 2 incidents – see Figure 8.

Figure 8: Water can be seen inside this enclosure, even though only one cable passes through each gland.

Another issue noted on 4 installations was the drilling of mounting holes through the back of enclosures designed to be weathertight (IP65). An example is shown in Figure 9. The hole on the top right-hand corner of the enclosure is outside of the weather seal and is designed to be used for a mounting screw without compromising the sealing. However, installers sometimes view drilling through the rear of the box as an easier option, most likely because of the types of screws they have to hand.

Figure 9: Rear of isolator enclosure drilled through for mounting screws. Note that the screw on the right hand side is rusty, indicating water ingress.

In at least 3 case, loose terminal connections were found during laboratory examination.

There were 12 instances of fires most likely caused by DC isolators for which the underlying reason is unknown. In some cases, there was more than one fault.

6.2 DC connectors and cables.

The second PV component most likely to be implicated as the cause of a fire is the DC connector: in 5 cases, the connectors were most likely the source of the fire, in a further 7 cases, they may have been the source.

The DC circuits connect the PV modules together, increasing the voltage in a similar way to connecting batteries in series. Parallel strings of PV modules increase the current. The DC circuits are fed back to the inverter, sometimes via a DC isolator. Figure 10 shows a simplified schematic diagram of the DC side of a typical small PV system. Larger systems have further parallel strings of PV modules and may also have fuses and junction boxes.

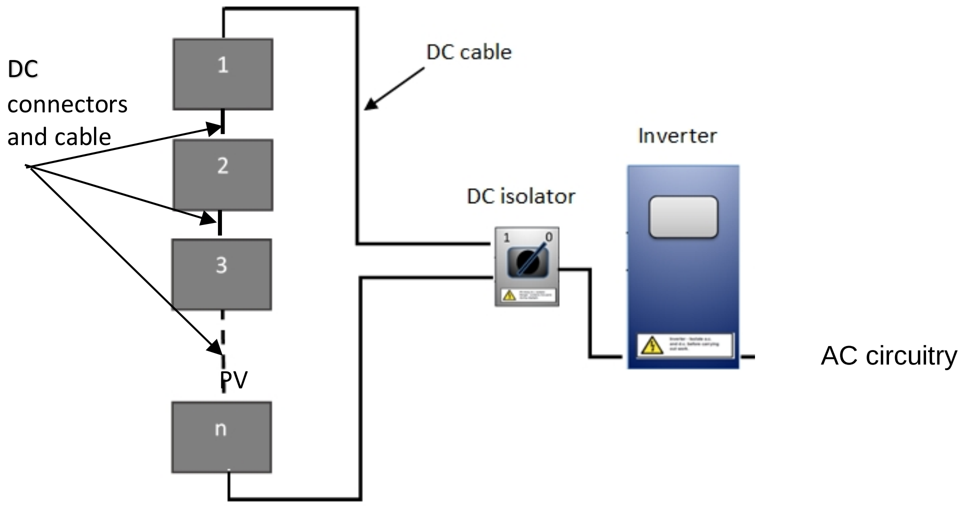


Figure 10: Simplified schematic diagram of DC components in a typical domestic PV system

As mentioned above, in some cases it is suspected that where a non-specialist (e.g. building owner, site manager or FRS) has supplied the information, the terminology may not be as precise as would be used by a PV specialist, and connectors are referred to as 'cables', adding some uncertainty to the number of fires where connectors or cables are thought to be responsible.

Figure 11 shows a typical 'MC4'-type DC connector – these are almost universally used on UK PV installations at this point in time. The metal contacts are crimped onto the ends of the cable and latched into place inside the plastic barrels. Both halves of the connector are touch-proof, improving safety for installation and maintenance crews. Barbs on the upper right hand image lock into slots on the other half to prevent the connector from accidentally separating once the two halves have been pushed together.

Figure 11: Typical (undamaged) DC connectors, separated (top image) and coupled (bottom image)

If the evidence can be accessed at the fire scene, it is often clear if a DC connector has been subject to electrical arcing – molten beads of contact material can usually be observed, as shown in Figure 12.

Figure 12: Example of DC connector contact that has been subject to electrical arcing. The right hand end has been melted.

The finding of such evidence does not necessarily mean that the component caused the fire, since the arcing may have occurred as a result of the fire. However, the experience of the investigating teams has been that the metal contacts of DC connectors tend to remain connected by frictional forces, even when the supporting plastic body has been burnt off – see Figure 5. Therefore, any DC connectors that have been subject to arcing should be suspected as a likely source of ignition.

6.3 Inverters

Inverters form the most complex part of a PV system and they have to actively manage the power continuously flowing through them. From this perspective, it is surprising that a greater proportion of the incidents are not caused by inverter fires. However, unlike DC isolators and connectors, they are 'intelligent' devices, with sophisticated sensors and safety features, and this helps to prevent catastrophic malfunctions.

Nevertheless, in the database there are currently 6 incidents of fires logged as initiating in an inverter and a further 3 incidents that *may* have been caused by inverters.

As with the connectors and cables, it is suspected that where a non-specialist has supplied the information, the terminology may not be as precise as would be used by a PV specialist. In some cases, it is possible that an isolator mounted near to an inverter has ignited but been reported as an 'inverter fire'.

Where an inverter has caught fire, the burn patterns observed at the scene often make this clear – see Figure 13.

Figure 13: Inverter fire with clear burn patterns showing this as the source of the fire.

Further corroborating evidence may be that there were no isolators mounted nearby, or if there were, their conducting parts have not been subject to arcing or resistance heating, and no evidence of arcing at the inverter connectors.

6.4 PV Modules

Where PV modules are the source of fire, there may be evidence of arcing within the remains of one or more of the modules – an example can be seen in Figure 14.

Figure 14: Damaged part of a PV module junction box laid over an identical undamaged component, showing where material has been ablated through arcing.

7 Fire & Rescue Services

7.1 Awareness

In most cases that the team has investigated (desk or site investigations), direct contact has been made with the relevant FRS, which have been supportive of the project. As a result of the majority of incidents logged involving a FRS the results are skewed more towards serious incidents, which have resulted in less certainty over exact cause (due to the extent of damage to systems and components).

It has been harder to engage with solar installers, with only a small proportion of the incidents being reported by a solar/ maintenance engineer. The number of thermal events (near-misses) may be higher than suggested by this research.

7.2 Issues reported by FRS

Issues for FRSs caused by PV systems when they were tackling fires (whether or not caused by the PV system) were reported in a total of 19 incidents.

The issues recorded are as follows:

- Potential for electrocution (6 reports) and 1 actual minor electrocution
- Fear of [roof] collapse and live cables
- Unable to isolate live PV cables. Towards the end of the incident, engineers were in attendance [not clear where engineers came from]
- Fire crews could not access the loft to isolate the PV system
- Access may have been slightly more difficult [with PV system in place]
- The roof had metal tiles and fire crews were concerned that a fault in the PV panels could result in the roof becoming live
- [The Distribution Network Operator] knew very little about these systems and how to make them safe. There were lots of uncertainties which made safe systems of work for fire service unpredictable
- After PV system made safe by installer, no issues [delay implied]

We had some particular assistance from Devon and Somerset FRS, who held a formal incident de-brief following one of the fires that the team investigated. We sent two representatives to the briefing and the key messages for the project were as follows:

- Fire crews need a method of making the PV system as safe as possible on arrival at the scene. Knowing the system remains live did not prevent the tackling of the fire, but it caused a short delay whilst a dynamic risk assessment was carried out and a suitable strategy put in place.

- Once the fire had been extinguished, the fire crews attempted to make the house as safe as possible and then hand over to the owner. However, there was concern that live DC cables were still exposed in the upper floor.

8 Conclusions

8.1 This report

This report, *Fire and Solar PV Systems – Investigations and Evidence* forms the published output from WP3 and 4 (see below). This report is an updated revision of the interim Investigation and Evidence report published by BEIS in July 2017.

In the report, background information is given before describing the main work packages making up the project. The methodology is described for the reviews, communications and data collection exercises involved.

A short explanation of electrical arcing is given. This is thought to be the main mechanism of ignition in fires originating in PV systems.

The findings of the data collection exercise are then presented, with a description of the sources of data, severity of fires, numbers and types of human casualties, building types and the PV components most likely to be implicated in the initiation of the fire.

A section on the interpretation of the evidence explains how the conclusions have been arrived at and a short section on feedback from the fire services assists with an understanding of their point-of-view and the issues they face when tackling a fire involving a PV system.

8.2 Project overview

Since its inception in July 2015, the project team has conducted several strands of research on the topic of PV-related fires. We have completed and reported the following outputs:

- A literature review identifying a total of 184 relevant papers
- A review of technical standards
- A review of relevant training courses
- A review of 33 historical fire incidents involving PV systems
- The design and initial population of a database of the historical incidents
- Investigations into 47 new fire incidents involving PV systems as they occurred, incorporating the data into the database

The public description of the project can be found on the following BRE NSC web page: http://www.bre.co.uk/nsc/page.jsp?id=3676. We have communicated with the PV industry via targeted articles in the trade press and communications via the Microgeneration Certification Scheme (MCS).

Communications with the fire and rescue community has mainly been via CFOA. The intention is to feed into the National Occupational Guidance system, as suitable reports are produced.

Fire incidents tend to be seasonal, allowing the project team to produce a set of reports over the winter months and to prepare for the next ‘season’ of investigations into PV-related fires, most likely beginning in April.

The reviews of historical incidents, relevant literature, standards and training are complete and have been reported separately [4]. Therefore, going forward the project activity will consist of investigations into new incidents by desk studies and site visits, further reporting and dissemination activities.

8.3 Summary of findings

A total of 80 unique incidents have been investigated and incorporated into the database:

- 33 are historical incidents, arising before the initiation of the project
- 21 of the incidents were investigated remotely ("desk investigations")
- 26 incidents were investigated on-site shortly after the incident had occurred
- 7 of the investigations include laboratory examinations of fire-damaged components

The severity of the fires varied. 22 of the incidents that were caused by PV systems were classified as 'serious' (i.e. difficult to extinguish and spreading beyond the PV system). 36 incidents were localised fires (affecting only PV components and the immediate area) or 'thermal events' (smoking or smouldering that did not develop into a fire).

In 16 incidents the cause was not thought to be the PV system and in 6 incidents, there was insufficient information to arrive at a reliable conclusion, so classified as 'cause unknown'.

In general therefore, PV fires have caused damage to PV installations themselves and sometimes to the buildings on which they are mounted. Fortunately, injuries appear to be mostly minor to date: 6 cases of smoke inhalation (treated at scene), 1 minor burn, 1 case of shock and 1 minor knee injury.

There are 3 fatalities recorded in the database, but the fire has not been as a result of the PV system.

The building types involved break down as follows:

- Domestic buildings 37 incidents
- Non-domestic buildings 37 incidents
- Solar farms 6 incidents

However, we strongly suspect a degree of under-reporting, especially amongst solar farms and domestic thermal events that were resolved by a solar installer/ maintenance engineer.

The review of international literature conducted under this project in 2015 [4], concluded that:

Where PV systems have been the cause of fires, some themes emerge. Much attention is paid to the phenomenon of electrical arcing, where a current flows across an air gap by ionising the air. High voltage arcs are extremely hot and can cause combustion of surrounding materials in less than a second. Arcing can occur where conducting parts become physically separated by mechanical movement or mis-alignment. Also, a build-up of contaminants (e.g. oxide) on electrical contacts can cause resistive heating, resulting in the breakdown of materials and subsequent arcing.

Certain components, if incorrectly specified, poorly installed or contain manufacturing faults, are typical locations of electrical arcs:

- *DC connectors*
- *DC isolators*
- *Inverters*
- *PV modules, including by-pass diodes and junction boxes*

The experience of investigating 47 recent incidents in the UK has resulted in very similar findings. The analysis of our database of incidents shows that the PV components most likely to develop faults that lead to a fire incident are as follows:

- DC isolators 26 - 28 incidents
- DC connectors 5 - 12 incidents
- Inverters 6 - 9 incidents
- DC cables 1 - 5 incidents
- PV modules 2 - 5 incidents
- DC combiner box 1 incident

In 4 cases, the origin of the fire was not traced to any particular component.

Approximately 36% of incidents recorded that were caused by PV systems were attributed to poor installation practices. 5% were attributed to faulty products and 10% to system design errors. The causes of the remainder were unknown.

A summarised, anonymised listing of the database records can be seen in Appendix B.

There are anecdotal reports of power diverters presenting new fire and safety risks. These devices divert excess electricity generated by solar panels to a specific load, such as an immersion heater. However, within this project, we have yet to encounter a fire that appears to have been caused by one of these devices, so the results so far do not support this assertion.

8.4 Challenges

Once the team has been made aware of a live or recent incident, an assessment is made as to whether the site should be visited, based upon the apparent involvement of the PV system. In cases where a site visit is indicated, the next step is to gain permission at access the site. This can be problematic as the owner of the building may not be identified - the FRS cannot pass on contact details without permission. In some cases, this can cause a delay of days or even weeks before we can speak with the owner and seek permission to visit. However, as the project progressed, the FRS generally obtained permission on site and passed on contact details in a timely manner, allowing us to complete more on site investigations.

A second challenge can be discovering who is investigating the scene on behalf of the building owner's insurance company. In each case we make efforts to determine the identity of the relevant fire investigator in order to coordinate the site visit, support each other's investigation and, ideally, to share resulting information. Our project colleagues at Fire Investigations UK have excellent contacts and relationships with all of the main forensic investigation companies, so this is of great assistance. However, the team has been denied access to one site by the insurance company's loss adjuster, so careful handling of this situation is called for.

Responding to incidents with little notice can be a challenge. Both personal and professional plans may need to be changed. However, the team accepts this as part of the project requirements and we can normally respond within 24 hours.

The database in its current form is rather rudimentary, making it time consuming to extract data and perform analysis. Some relatively minor upgrades to the functionality of the database would allow more efficient processing and analysis of incident characteristics. We have recently introduced an anonymising print-out function that is useful for reporting.

References

[1] IET, “Code of Practice for Grid Connected Solar Photovoltaic Systems,” IET Standards, London, 2015.

[2] Microgeneration Certification Scheme, “Guide to the installation of photovoltaic systems,” Electrical Contractor's Association, London, 2012.

[3] “National Operational Guidance Programme,” London Fire Brigade, [Online]. Available: http://www.ukfrs.com/. [Accessed 02 02 2017].

[4] S. Pester and S. Woodman, “Fire and Solar PV Systems. Literature Review, Standards and Training,” BRE National Solar Centre, Watford, 2017.

[5] S. Pester and C. Coonick, “Fire and Solar PV Systems. Recommendations for the PV industry,” BRE National Solar Centre, Watford, 2017.

[6] S. Pester, C. Holland and C. Coonick, “Fire and Solar PV Systems. Recommendations for fire and rescue services,” BRE National Solar Centre, Watford, 2017.

[7] S. Pester, “DC isolators for photovoltaic systems - a good practice guide,” IHS BRE Press, Bracknell, 2014.

[8] S. Pester, “Fire and Solar PV Systems. Investigations and evidence,” BRE National Solar Centre, Watford, 2017.

Appendix A Database description

Database fields

The database consists of a set of some 73 fields per record. Each record pertains to one incident and is given a unique reference number, of the form PVFxxxx, where xxxx is a serial number.

The field headings for each incident record are as follows:

Site Owner / occupier
Address
How did you become aware of this incident?
Date of incident
Time of incident (hh:mm)
Thought to be caused by PV, or PV just present?
Type of installation (Domestic/Non-domestic/Solar farm)
Was the local FRS called?
If no, how was the fire dealt with?
Severity of incident
Type of building
No. of storeys
Type of construction (if known)
Type of roof
If Other, please specify
Age of property
Location of PV array
Location of inverter
Location of isolation switches
General conditions
Wind speed
Wind direction
Precipitation (mm rain)
Irradiance (if known)
Was the property occupied at the time of the fire?
No. of evacuations (if any)
How were the occupants alerted to the fire?
Nature, extent and number of any injuries as a result of the fire?
Extent of fire spread/damage
Any issues with building performance (e.g. collapse, issues with compartmentation, etc.)
Provisional or recorded cause of fire
If PV system, components thought to be involved
Evidence to support likely cause
Any other comments on cause
Date system commissioned
Records of any maintenance (When and type of maintenance)

Is this a BIPV (built-in PV) system		
Any comments on DC connectors and cabling (e.g. condition, damage away from fire)		
System components	Make	Model
Modules		
Mounting		
Inverter(s)		
DC isolator		
Remote DC switches		
DC connectors		
DC Cable		
DC overcurrent protective devices		
AC cable		
AC protective devices		
Surge protection		
Other		
Type of fire alarm system installed (if any)		
Detector fitted specifically for PV system?		
If yes, please select type of detector installed		
Was the detector linked to the main alarm system?		
Location of detector for PV system		
Any other active fire protection systems installed (e.g. suppression systems)		
If yes, please provide details of other fire protection systems		
Remote DC switching device involved		
Arc fault detection involved		
Earth fault (insulation fault) alarm involved		
Did any of the systems mentioned in this section operate?		
If yes, please specify		
Was there a Solar PV on roof label in place near the main consumer unit/distribution board?		
Were the crews aware of the presence of the PV system on arrival?		
Did crews notice a Solar PV on roof label near the main electrical intake?		
If yes, did this change tactics for fighting the fire?		
If yes, how were the tactics changed?		
Did crews take any action(s) to make the PV system safe?		
If yes, please specify:		
Did the PV system cause any particular hazards for fire crews?		
If yes, please specify:		
Does your service have a Standard Operating Procedure or use any other guidance for dealing with fires involving PVs?		
Did the presence of the PV system exacerbate the fire in any way?		

Appendix B shows an anonymised summary of the current data set.

User interface

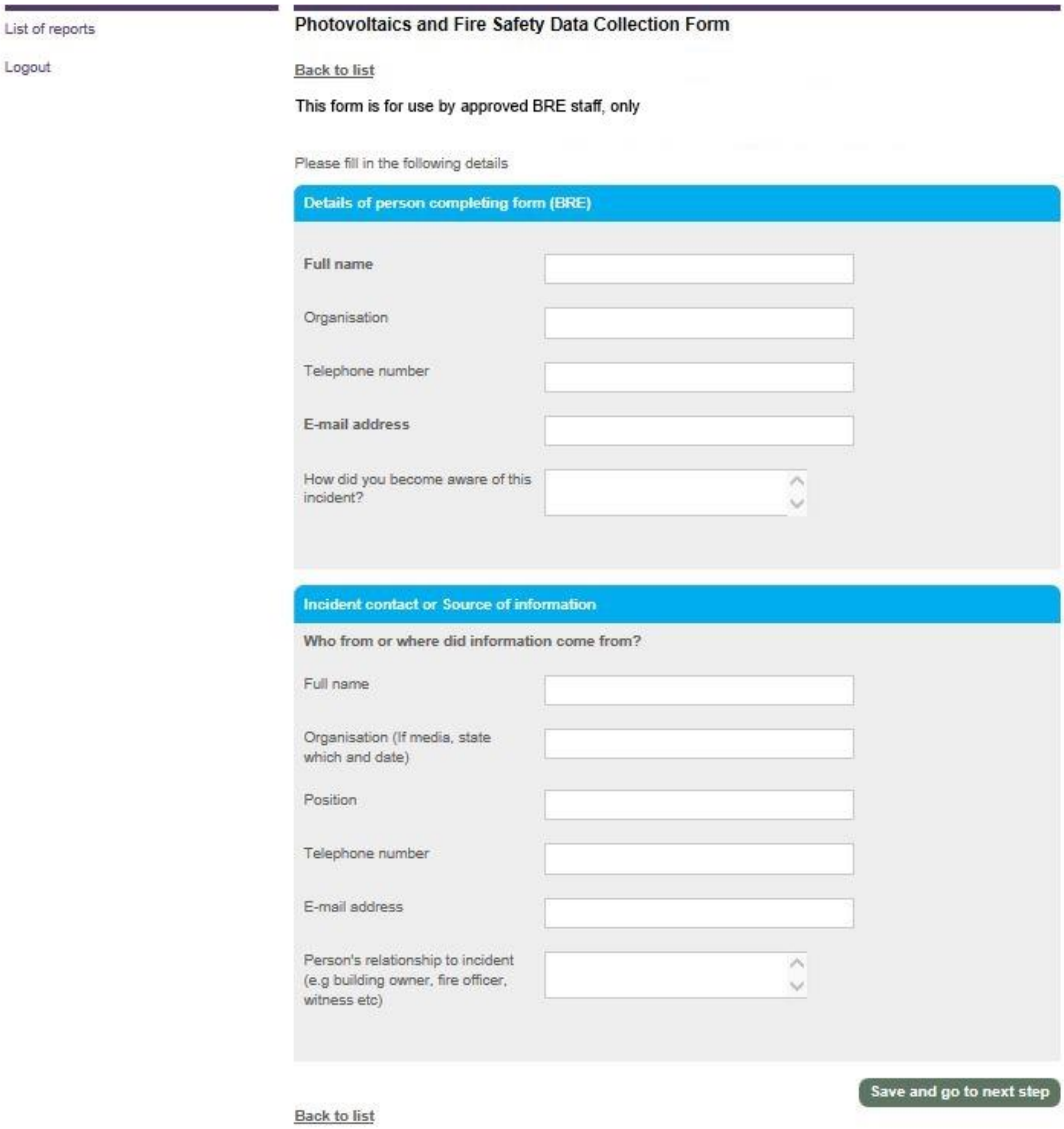
The first screen encountered when entering the portal is the listing. This shows a summary of all database records in short form. The screen shot below shows the listing page with sensitive data redacted.

Full name	ID	Organisation	Email address	Phone number	Date of incident	Address of incident	
Steve Pester	PVF0041	BRE National Solar Centre	steve.pester@bre.co.uk	01923 664 729	[redacted]		view
Steve Pester	PVF0040	BRE-NSC	steve.pester@bre.co.uk	01923 664 729			view
Steve Pester	PVF0039	BRE-NSC	steve.pester@bre.co.uk	01923 664 729			view
Steve Pester	PVF0038	BRE National Solar Centre	steve.pester@bre.co.uk	01923664729			view
Chris Coonick	PVF0037	BRE	coonickc@bre.co.uk	07890256131			view

Each record is automatically assigned the unique identifier (“ID” column). The ‘view’ link on the right hand side provides access to the full record for each incident.

After the listing page, the user can opt to enter a new record, the first page of which is shown in the next screen shot:

Page 1:


List of reports

Logout

Photovoltaics and Fire Safety Data Collection Form

Back to list

This form is for use by approved BRE staff, only

Please fill in the following details

Details of person completing form (BRE)

Full name

Organisation

Telephone number

E-mail address

How did you become aware of this incident?

Incident contact or Source of information

Who from or where did information come from?

Full name

Organisation (If media, state which and date)

Position

Telephone number

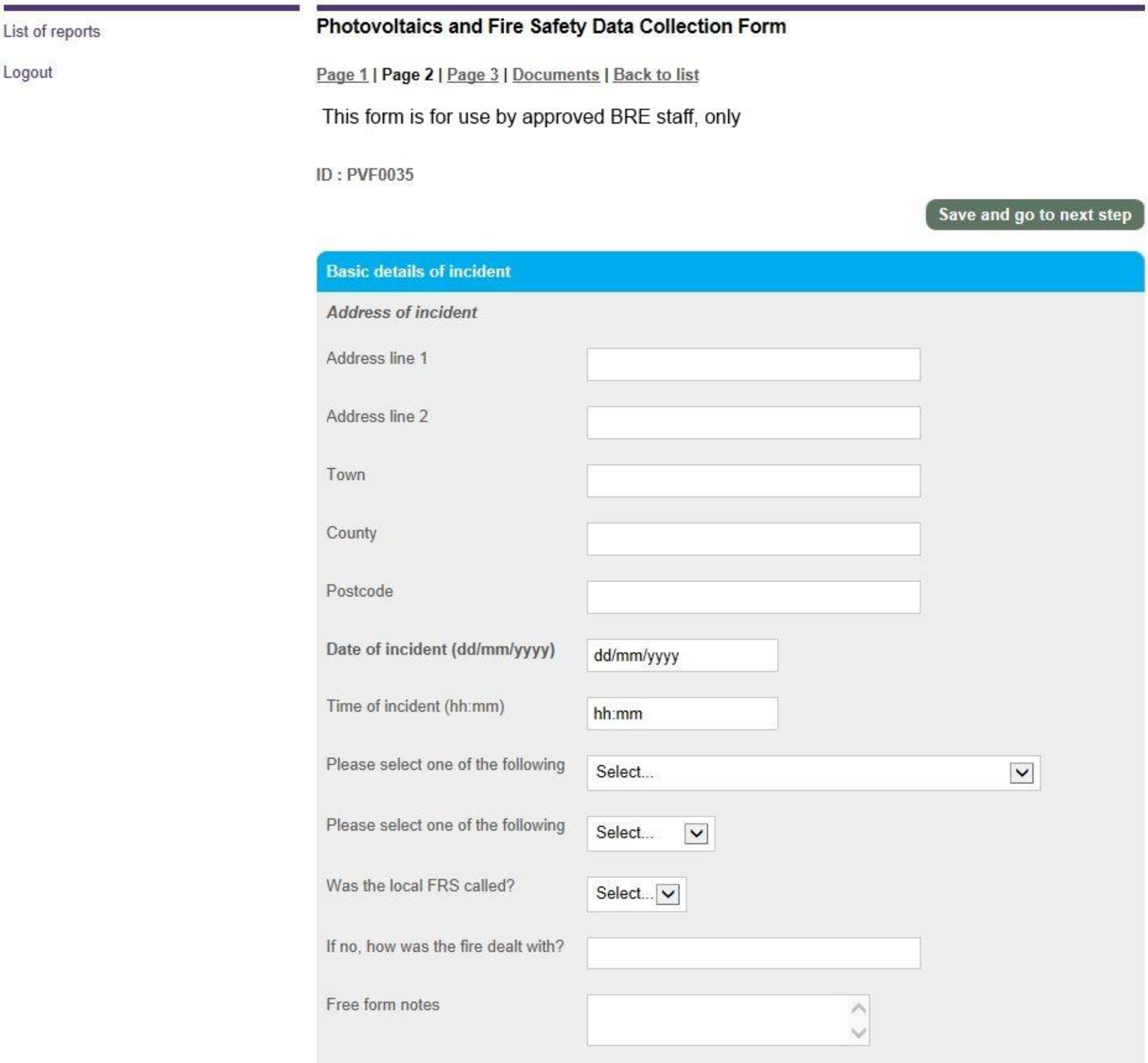
E-mail address

Person's relationship to incident (e.g building owner, fire officer, witness etc)

Save and go to next step

Back to list

The remaining incident data is input on pages 2 and 3, as shown in the following screen shots:


List of reports

Logout

Photovoltaics and Fire Safety Data Collection Form

Page 1 | **Page 2** | Page 3 | Documents | Back to list

This form is for use by approved BRE staff, only

ID : PVF0035

Save and go to next step

Basic details of incident

Address of incident

Address line 1	
Address line 2	
Town	
County	
Postcode	
Date of incident (dd/mm/yyyy)	dd/mm/yyyy
Time of incident (hh:mm)	hh:mm
Please select one of the following	Select...
Please select one of the following	Select...
Was the local FRS called?	Select...
If no, how was the fire dealt with?	
Free form notes	

Fire and Rescue Service intervention

FRS in attendance (Name of Fire and Rescue Service)

FRS Incident No. (if known)

Details of Officer in Charge of incident (either during the incident or lead fire investigator)

Full name

Role in relation to the incident

Detailed information on the incident

Type of incident (please select) — Select...

Building description (where a building is involved)

Type of building — Select...

No. of storeys — 0

Height of building — Select...

Type of construction (if known) — Select...

Type of roof — Select...

If Other, please specify

Age of property

Location of PV array

Location of inverter

Location of isolation switches

Weather at time of incident

General conditions		
Wind speed	0.0	m/s
Wind direction		
Precipitation	0.0	mm rain
Irradiance (if known)	0.0	W/m²

Description of the fire

Was the property occupied at the time of the fire?	Select...
No. of evacuations (if any)	
How were the occupants alerted to the fire?	
Nature, extent and number of any injuries as a result of the fire?	
Extent of fire spread/damage	
Any issues with building performance (e.g. collapse, issues with compartmentation, etc.)	

Save and go to next step

Page 1 | **Page 2** | Page 3 | Documents | Back to list

List of reports

Logout

Photovoltaics and Fire Safety Data Collection Form

Page 1 | Page 2 | **Page 3** | Documents | Back to list

ID : PVF0035

Save and complete

Initial assessment of cause of fire

Provisional or recorded cause of fire: Select...

If PV system, please select components thought to be involved:

- ☐ DC isolator
- ☐ DC connectors
- ☐ DC cables
- ☐ Inverter
- ☐ Module
- ☐ Mounting
- ☐ AC cable

Evidence to support likely cause

Any other comments on cause

System description

Date system commissioned (dd/mm/yyyy): dd/mm/yyyy

System installer:

Records of any maintenance (When and type of maintenance):

Is this a BIPV (built-in PV) system: Select...

Any comments on DC connectors and cabling (e.g. condition, damage away from fire):

System components	Make	Model
Modules		
Mounting		
Inverter(s)		
DC isolator		
Remote DC switches		
DC connectors		
DC Cable		
DC overcurrent protective devices		
AC cable		
AC protective devices		
Surge protection		
Other		

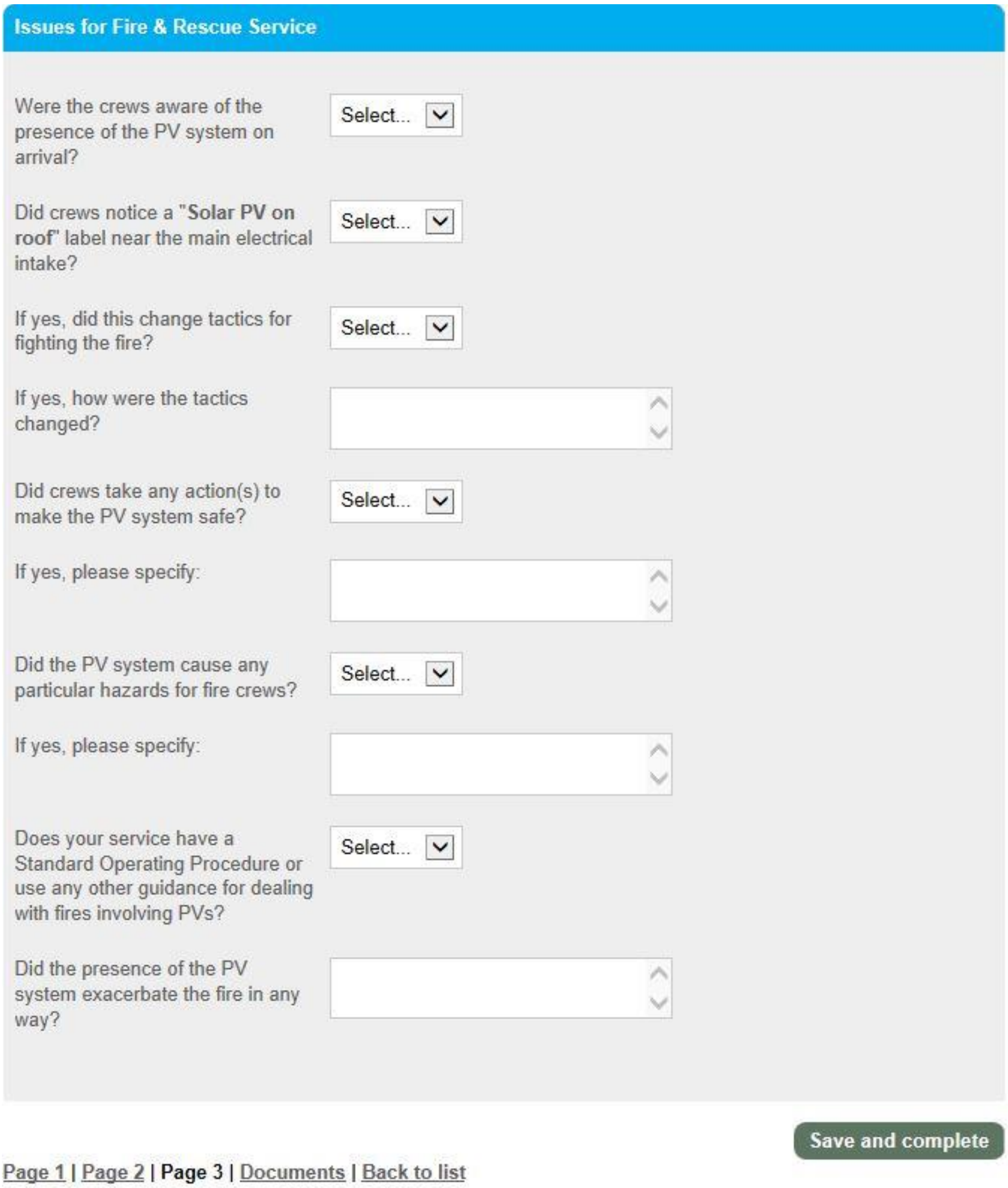
Fire protection equipment

Type of fire alarm system installed (if any)	
Detector fitted specifically for PV system? -1	Select...
If yes, please select type of detector installed	Select...
Was the detector linked to the main alarm system?	Select...
Location of detector for PV system	
Any other active fire protection systems installed (e.g. suppression systems)	Select...
If yes, please provide details of other fire protection systems	

Were any of the following installed (please tick all that apply):

- ☐ Remote DC switching device
- ☐ Arc fault detection
- ☐ Earth fault (insulation fault) alarm

Did any of the systems mentioned in this section operate?	Select...
If yes, please specify:	
Did the fire protection systems installed operate as expected/designed?	Select...
If no, please specify why:	
Was there a "**Solar PV on roof**" label in place near the main consumer unit/distribution board?	Select...



Issues for Fire & Rescue Service

Were the crews aware of the presence of the PV system on arrival?	Select...
Did crews notice a "**Solar PV on roof**" label near the main electrical intake?	Select...
If yes, did this change tactics for fighting the fire?	Select...
If yes, how were the tactics changed?	
Did crews take any action(s) to make the PV system safe?	Select...
If yes, please specify:	
Did the PV system cause any particular hazards for fire crews?	Select...
If yes, please specify:	
Does your service have a Standard Operating Procedure or use any other guidance for dealing with fires involving PVs?	Select...
Did the presence of the PV system exacerbate the fire in any way?	

Save and complete

Page 1 | Page 2 | **Page 3** | Documents | Back to list

After this final screen of input data, the user may also attach related documents, e.g. reports, photographs, witness statements, etc.

The screen for attaching documents is shown in the next screen shot with example documents loaded.

Photovoltaics and Fire Safety Data Collection Form

Page 1 | Page 2 | Page 3 | **Documents** | Back to list

ID : PVF0056

Evidence - photos and documents

Description	Type of document	Filename		
Photo from site investigation	Image	image1.jpg	edit	delete
Photo from site investigation	Image	image2.JPG	edit	delete
Tech data sheets on components	Technical data	Section-003--Manufacturers-Literature.pdf	edit	delete

Add document

Page 1 | Page 2 | Page 3 | **Documents** | Back to list

Please note that in some cases not all of the database fields can be populated since the information is not always available. However, the team attempts to gather as much information on each incident as possible.

Appendix B Summary listing of records (anonymised)

Incident Ref	Site Visit	Desk Study	Lab bench exam	Incident cause attributed to PV system?	Site Type	Severity	If PV system, components thought to be involved	Most likely root cause
PVF0001	Y			Y	Commercial	Serious	DC connectors, Module, Mounting	Faulty product
PVF0002				Y	Domestic	Localised	Unknown	Unknown
PVF0003				Y	School	Localised	DC isolator	Poor installation
PVF0004				N	Domestic	Serious	N/A	N/A
PVF0005	Y		Y	Y	Domestic	Thermal event	DC isolator	Poor installation
PVF0006				Y	Commercial	Thermal event	DC isolator	Unknown
PVF0007				Y	Domestic	Serious	DC isolator	Unknown
PVF0008				Y	Domestic	Serious	Unknown	Unknown
PVF0009				Y	Commercial	Thermal event	DC isolator, Inverter	Unknown
PVF0010				Y	Domestic	Thermal event	Unknown	Unknown
PVF0011				N	Domestic	Serious	N/A	N/A
PVF0012				N	Domestic	Serious	N/A	N/A
PVF0013				Y	Commercial	Localised	DC isolator	Unknown
PVF0014				N	Domestic	Serious	N/A	N/A
PVF0015				N	School	Serious	N/A	N/A
PVF0016				N	Commercial	Serious	N/A	N/A
PVF0017				Unknown	Domestic	Localised	Unknown	Unknown
PVF0018				Y	Solar farm	Localised	Unknown	Unknown
PVF0019				Y	School	Serious	Unknown	Unknown
PVF0020				Unknown	Solar farm	Localised	Unknown	Unknown
PVF0021				Y	Domestic	Serious	DC isolator	Unknown
PVF0022				Unknown	Domestic	Serious	Inverter	Unknown
PVF0023				Y	Domestic	Serious	Unknown	Unknown
PVF0024				Unknown	Commercial	Localised	Unknown	Unknown
PVF0025				N	Domestic	Serious	N/A	N/A
PVF0026				N	School	Serious	N/A	N/A
PVF0027				N	Domestic	Serious	N/A	N/A
PVF0028				Y	School	Localised	DC cables	Unknown

PVF0029 Record deleted								
PVF0030				Y	Solar farm	Localised	Inverter	Unknown
PVF0031				Y	Solar farm	Localised	Inverter	Faulty product
PVF0032				Y	Domestic	Serious	Inverter	Unknown
PVF0033				Unknown	Commercial	Localised	Unknown	Unknown
PVF0034				Unknown	Domestic	Localised	Unknown	Unknown
PVF0035		Y	Y	Y	Commercial	Thermal event	DC isolator	Poor installation
PVF0036				Y	Domestic	Serious	DC isolator	Unknown
PVF0037		Y		Y	Commercial	Localised	DC isolator	System design issue
PVF0038				Y	School	Serious	DC connectors, Mounting	Unknown
PVF0039	Y		Y	Y	Commercial	Localised	DC isolator	Poor installation
PVF0040		Y		Y	Commercial	Localised	Unknown	Unknown
PVF0041	Y		Y	Y	Commercial	Localised	DC isolator	Poor installation
PVF0042		Y		Y	Hospital	Localised	DC connectors, DC cables	Poor installation
PVF0043		Y		N	School	Serious	N/A	N/A
PVF0044		Y		Y	Domestic	Serious	DC connectors, Inverter	Unknown
PVF0045		Y		Y	School	Localised	DC isolator	Unknown
PVF0046		Y		Y	Domestic	Thermal event	Module	Faulty product
PVF0047		Y	Y	Y	Domestic	Thermal event	DC isolator	Faulty product
PVF0048		Y		Y	Commercial	Thermal event	DC connectors	Poor installation
PVF0049		Y		Y	Commercial	Localised	DC isolator	System design issue
PVF0050		Y		Y	Solar farm	Thermal event	DC connectors	Poor installation
PVF0051	Y			Y	Domestic	Serious	DC isolator	Unknown
PVF0052	Y			Y	Domestic	Serious	Inverter	Faulty product
PVF0053	Y		Y	Y	Commercial	Localised	DC isolator, DC connectors	Poor installation
PVF0054	Y			Y	Domestic	Serious	DC connectors	Poor installation
PVF0055	Y			Y	Domestic	Serious	DC connectors, DC cables	Poor installation
PVF0056	Y			Y	Commercial	Serious	DC connectors	Poor installation
PVF0057	Y			Y	Domestic	Serious	DC connectors, DC cables	Unknown
PVF0058	Y		Y	Y	School	Localised	DC isolator	Poor installation
PVF0059		Y		Y	Domestic	Serious	Inverter	Unknown

PVF0060	Y			N	Domestic	Localised	N/A	N/A
PVF0061		Y		Y	Domestic	Serious	DC isolator, AC isolator, inverter	Unknown
PVF0062	Y			N	Residential home	Serious	N/A	N/A
PVF0063		Y		Y	Solar farm	Localised	DC combiner box	Poor installation
PVF0064		Y		Y	Domestic	Serious	Unknown	Unknown
PVF0065	Y			Y	Domestic	Serious	DC isolator, DC connectors	Unknown
PVF0066	Y			Y	Domestic	Serious	DC connectors, Module, Mounting	Unknown
PVF0067	Y			N	Domestic	Serious	N/A	N/A
PVF0068		Y		Y	Industrial	Localised	Module	System design issue, faulty product
PVF0069		Y		Y	School	Localised	DC isolator	N/A
PVF0070		Y		N	Domestic	Serious	N/A	N/A
PVF0071	Y			Y	Leisure centre	Localised	DC isolator	Poor installation, faulty product
PVF0072	Y			Y	Leisure centre	Localised	DC isolator	Poor installation, faulty product
PVF0073		Y		Y	School	Localised	DC isolator	Poor installation, faulty product
PVF0074		Y		Y	Residential home	Localised	DC isolator	Poor installation, faulty product
PVF0075	Y			Y	Residential home	Localised	DC isolator	Poor installation, faulty product
PVF0076	Y			N	Industrial	Serious	N/A	N/A
PVF0077		Y		Y	Domestic	Serious	DC isolator, inverter	System design issue, poor installation
PVF0078		Y		Y	Commercial	Localised	DC isolator	Poor installation, faulty product
PVF0079		Y		Y	Commercial	Localised	DC isolator, DC cable	Poor installation, system design issue
PVF0080		Y		N	Domestic	Serious	N/A	N/A
PVF0081		Y		Y	Domestic	Thermal event	DC isolator	Poor installation, faulty product

Appendix C Laboratory examination report - example 1

CASE No: [redacted]-BRE Solar Project
BRE Ref:

Scene Examination Report

1. Synopsis

1.1. **FIUK Case No.** [redacted] BRE Solar Project – [redacted] – Laboratory Examination.

1.2. **Address of fire:** [redacted].

1.3. **Date and time of incident:** 10 February 20[redacted] at 10:54.

1.4. **Date and time investigation commenced:** 1 March 20[redacted] at 09:00.

1.5. **Fire Investigator:** [redacted].

1.6. **Client:** [redacted] BRE Solar.

1.7. **Reason for instruction:** To determine the origin and cause of a fire involving a photovoltaic installation. This report should be read in conjunction with the scene examination report.

1.8. **Equipment description:** the equipment subjected to forensic examination consisted of three DC isolators identified as RHB 1, RHB 2 (collected from the premises of the PV system installers and labelled as exhibit [redacted]) and LHB 1 (collected from the fire scene and labelled as exhibit [redacted]). A third exhibit (collected from the fire scene and labelled as [redacted]) consisted of DC isolator remains found on the ground below the original positions of DC isolators RHB 1 and RHB 2.

1.9. **Summary:** This report determines that the damage to the DC isolators examined is consistent with abnormal electrical activity occurring within the DC isolator enclosures generating sufficient heat energy to cause ignition of adjacent materials.

1.10. **Photographs:** Those photographs mentioned in the text of this report are enclosed in this report. Photographs were taken using a Pentax WGIII digital camera.

2. Sequence of events

2.1. On the 10 February 2016 at approximately 10:50, a delivery lorry was driving along the road outside the [redacted] site, toward the entrance, when the driver noted a fire on the outside wall of the [redacted]. The driver alerted members of the public who were outside the entrance to the [redacted] to the situation. The members of the public then notified a [redacted] staff member.

2.2. The staff member attended the scene with Carbon Dioxide and Dry Powder fire extinguishers that were used to extinguish the fire. Other members of [redacted] staff also attended the scene and the [redacted] Fire and Rescue Service [redacted]) were called.

1

2.3. The [redacted] arrived at the scene at 11:16 and as the fire had been extinguished they carried out checks using a thermal imaging camera (TIC), established a cordon around the scene and turned all the isolators to the 'OFF' position. They also sent a message to their mobilising control reporting that the fire was due to "water ingress at the inverter isolation points".

2.4. The [redacted] staff contacted the installers of the system, [redacted], who attended the scene later that afternoon and removed the affected DC isolators, the inverter located above and they also cut and taped a number of DC conductors that had been attached to the affected isolators.

2.5. Following a visit to the installers, [redacted], and a scene examination at [redacted], a number of exhibits (detailed above) were retained for a laboratory forensic examination.

3. Laboratory examination

3.1. **Exhibit [redacted]**

3.2. This exhibit packaging contained the remains of DC isolators RHB 1 and RHB 2.

3.3. The remains of RHB 1 consisted of a small section of a light coloured plastic, identified as the rear of the enclosure, with a mounting screw. This particular exhibit was unremarkable.

3.4. An examination was carried out of RHB 2. This DC isolator had been located to the immediate right of RHB 1. The enclosure had sustained fire damage and melting of the plastic to the left hand side and top sections. The pattern of fire damage to RHB 2 was consistent with fire spread from RHB 1 (see Figures 1 & 2).

3.5. **Exhibit [redacted]**

3.6. This exhibit consisted of debris collected from the ground below the original location of DC isolators RHB 1 and RHB 2 (see Photograph 3). Within this debris, amongst the sections of burnt and melted plastic, were metal screw terminals. It was determined that these had most probably been originally associated with DC isolator RHB 1 as the enclosure of RHB 2 had retained much of its integrity.

3.7. The screw terminal remains examined exhibited metallic deposits in the area of the terminal screw. This is indicative of abnormal electrical activity (see Figure 4).

3.8. The remains of a further metallic component, possibly a terminal connection, were noted to be heavily oxidised. However consideration must be given to the fact that this item had remained exposed to the elements prior to collection (see Figure 5).

3.9. Other items examined from this debris included short lengths of DC conductor. One of the short lengths of conductor displayed evidence of arcing.

3.10. **Exhibit [redacted]/3**

3.11. This exhibit consisted of the fire damaged DC isolator that was responsible for the third fire event identified during the scene examination.

2

3.12. Once opened the internal surfaces of the enclosure were found severely contaminated with the products of combustion. The internal switching unit was removed for examination (see Figures 6 & 7).

3.13. The 'jumper links' were fitted to the top connections of L1 and L2 and of L3 and N. These connections were found tight and relatively undamaged (see Figure 8).

3.14. The lower connections were identified as T1 (positive out), T2 (positive in), T3 (negative in) and N (negative out).

3.15. The cables from the array feeding the DC isolator had entered from the bottom glands with the feed out exiting from the top to connect to the inverter.

3.16. Examination of the damage to the external switching unit revealed the greatest damage, causing melting and burning to the plastic, in the vicinity of T2 and T3, the permanently live conductors (see Figures 9 & 10).

4. Conclusion

4.1. Based on the findings of the scene examination carried out at [redacted] and the forensic laboratory examination of the exhibits, I am of the opinion that the three fire events, affecting the PV installation, were as a result of water ingress into the enclosure of the DC isolators.

4.2 Once the water has entered the enclosure a conductive path was established between the positive and negative conductor terminals causing arcing and generating heat. The heat would have degraded the plastic materials adjacent to the arcing event, which have subsequently ignited.

Report prepared by:

[redacted] [redacted]
Fire Investigations (UK) LLP

[redacted]

 Figure 1	 Figure 2
 Figure 3	 Figure 4
 Figure 5	 Figure 6
 Figure 7	 Figure 8

4

Figure 9

Figure 10

bre NATIONAL SOLAR CENTRE

Appendix D Laboratory examination report - example 2

bre FI UK Fire Investigations

CASE [redacted]

Bench Top Examination Report

1. **Synopsis**

   1.1. **Address of fire:** [redacted].

   1.2. **Date and time of call:** [redacted] shortly before 09:00.

   1.3. **Date and time investigation commenced:** [redacted]

   1.4. **Fire Investigator:** [redacted]

   1.5. **Information from the fire & rescue service:** [redacted] FRS attended (three appliances). No further details have currently been provided.

2. **PV Installation**

   2.1. The array was installed on [redacted] [redacted] 2011, by [redacted] MCS Installer Certificate Ref: [redacted]. The array had a declared capacity of 3.42 kW comprising 18 [redacted] 190W [redacted] modules and a [redacted] Invertor. System details provided with my instructions show that the array was arranged with two strings, each containing nine modules.

   2.2. Photographs provided with my instructions show that the [redacted] Invertor, AC Isolator, two DC Isolators and the Generation Meter were all mounted within a metal electrical cabinet that was attached to the exterior of the property (see Figures 1 and 2). The DC cables were routed on the exterior of the property within protective conduit (this appears to be metal but cannot confirmed).

   2.3. Photographs taken of the fire damaged installation show localised fire damage to one of the two DC Isolators, mounted in the bottom left hand corner of the cabinet. Both DC Isolators have been submitted for examination.

3. **Key observations**

   3.1. The DC isolators were identified as the [redacted] Enclosed DC rated switch disconnector manufactured by [redacted]. The two DC isolators are both rated at 16 Amps and 500 Volts DC (Model [redacted]) (see Figures 3 and 4). The switching mechanism is a 4-pole isolator that utilises a contact bridge mechanism. The isolator was originally manufactured for use in AC systems (identified by the terminal labelling designations namely L1, L2, L3 & N), however, it has been rated and certified for use in DC systems by the manufacturer [redacted] by pairing the switching contacts.

   3.2. The array fitted was 18 [redacted] 190W modules arranged into two strings. Information with my instructions details that the modules had a rated output of $V_{oc\,(STC)}$ 45.6 Volts and an $I_{sc\,(STC)}$ 5.8 Amps.

1

Therefore, the maximum voltage and current generation can be calculated using the following formulas:

PV String Switch Disconnector – Current Rating:

String Short-Circuit Current x 1.25

5.8 x 1.25 = **7.25 Amps**

PV String Switch Disconnector – Voltage Rating:

String Open-Circuit Voltage x 1.15

(9 x 45.6) x 1.15 = **472 Volts**

The [redacted] DC Isolator was operating within its design specification (16 Amps and 500 Volts).

3.3. The DC isolators had been installed within the electrical cabinet using the intended fixing points which did not compromise the weather proof rating of the switch enclosure.

3.4. The four DC cables (4mm² core diameter) were routed through a single M25x1.15 gland, secured to the top of the isolator enclosure (see Figure 5).

3.5. Within the enclosure 3-poles from the switch mechanism had been wired in series using two insulated link cables. The isolator had been wired so that 3-poles were used to switch the positive and 1-pole was used to switch the negative (see Figure 6). Both the fire damaged isolator (exhibit [redacted]) and the exemplar (exhibit [redacted]) were wired identically in terms of terminal configuration and gland position.

3.6. The fire damaged isolator enclosure (exhibit [redacted]) showed localised damage to the top right-hand corner, affecting the top, right-hand side and rear of the enclosure. The front of the enclosure was mostly undamaged. The four DC cables had been severed by electrical arcing activity within the enclosure. The switch mechanism showed the greatest fire damage to the bottom right-hand corner (highlighted in pink on Image 1).

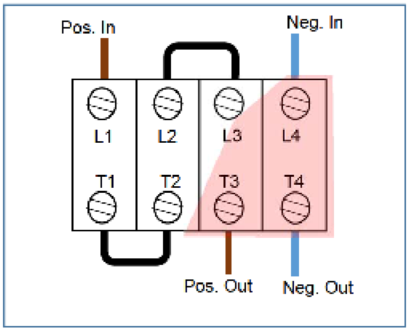


Image 1: Schematic showing the configuration and terminal designation of the switch mechanism inside the DC Isolator.

2

3.7. The head of the screw terminal L4 showed metallic deposits where it had melted from erroneous electrical arcing activity that had occurred between the L3 link cable and L4 cable (see Figure 7). The terminal clamp from L4 was less damaged and showed that there had been no excess heat generated at the point of connection; there was extensive melting to the L4 terminal switch contact (see Figure 8). The contact bridge from poles three and four had not been recovered or had been destroyed due to electrical arcing activity inside the switch mechanism. There was evidence of further melting and erroneous electrical activity to terminal T4, again the damage was far more extensive to the switching contact rather the connection between the cable and clamp (see Figure 9).

3.8. The second DC isolator (exhibit [redacted]) mounted on the right-hand side of the fire damaged isolator, showed minor fire damage to the exterior of the left-hand side of the enclosure. There was evidence of corrosion from water ingress inside the four DC cable terminals, this was most extensive in terminals L4 and T4 (see Figure 10). This may be a consequence of fire-fighting activities rather than weather exposure; it is not possible to exclude that the water ingress resulted from weather exposure, however the weatherproof enclosure and the use of conduit around the DC cables suggest this is less likely.

3.9. Inside the switch mechanism of exhibit [redacted], there was evidence of heat discolouration to both the fixed switching contacts from each terminal and the movable switching bridge contacts (see Figure 11). There was also evidence of minor scorching to the plastic bridge mechanism (see Figure 12).

3.10. There was also evidence of minor pitting to the contact pads on each of the switch terminals, this was consistent with the formation of a switching arc during opening and closing. The switching contact in terminal L2 appeared to show greater damage than the other neighbouring contacts. The non-movable switching terminal L2 appeared to be set slightly higher than terminals L1 and L3 this could cause this pole within the switch mechanism to make and break the full voltage fractionally before the other contacts, this could accelerate the rate of wear within the contact.

4. Conclusion

4.1. The fire has originated inside the switching mechanism for this DC isolator, the greatest damage has occurred within the mechanism used to switch the negative. Excessive heat has been generated at the switching contact point. The damage to the terminals is not consistent with the effects of restive heating having occurred between the terminal connection and the DC cable. Electrical activity within the negative switching pole has likely charred the plastic casing separating the poles within the switching mechanism. Arcing between the negative and neighbouring positive pole has then occurred within the switching mechanism. As the fire has developed further arcing between positive and negative cables outside of the switching mechanism but within the DC enclosure has occurred.

4.2 [redacted] product data sheet for the [redacted] isolator includes a circuit diagram showing the isolator wired in a balanced configuration using two poles to switch the positive and two poles to switch the negative. The actual installation appears to differ from the manufacturer's guidance, this could have a detrimental effect on the switching capabilities of the isolator.

4.3 There was evidence of water ingress inside the exemplar switching mechanism, however it is not possible to confirm if this was present before the fire occurred. The exemplar isolator shows excess heat has been generated around each of the switching contacts this has caused discolouration to the metal terminals, scorched the plastic bridging mechanism and evidence of minor pitting to the switching contacts. This heat discolouration appears to be a consequence of general use given that the [redacted] isolator was appropriately rated for this array.

Report prepared by: [redacted]
Fire Investigations (UK) LLP

Signature: [redacted]

4

 Figure 1	 Figure 2
 Figure 3	 Figure 4
 Figure 5	 Figure 6

5

 Figure 7	 Figure 8
 Figure 9	 Figure 10
 Figure 11	 Figure 12

Report Ends

Exhibit 8

How Solar Farm Fires Can Damage the Environment

October 11, 2022 | By Firetrace International

A fire at a solar farm can result in pollution as well as posing a serious threat to human life and health – consequently it's vital you protect your solar project from fire risk.

A fire at a solar farm can have devastating consequences for the surrounding environment. This is in addition to the obvious risks fires pose to human health. The damage can include air pollution, water pollution, fatalities, bronchitis, the exacerbation of asthma, and other lung diseases in the local population.

How Big Can Solar Fires Get?

Despite studies showing that the prevalence of solar farm fires may be underreported, there have been known instances of fire events in the solar sector that have caused significant damage to the surrounding environment.

Have you ever wondered what happens when a solar farm catches on fire? Well, earlier this year there was a solar farm fire in Australia that resulted in the loss of an area of grassland totaling five hectares, which is roughly equivalent to **12 NFL football fields**. In this instance, it took the local fire department an hour and a half to get fire under control. With the remoteness of many solar farm locations, it can be challenging for firefighters to get to the scene of a fire in a short timeframe.

What Damage Can Solar Farm Fires Do to the Surrounding Environment?

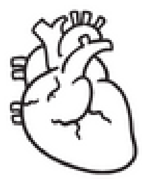
Here are three ways in which a solar farm fire could cause serious damage to the surrounding environment and the local population:

1. Polluted Water Supply

Stormwater runoff has been highlighted as one of the most noticeable impacts of forest fires. After vegetation has been destroyed by fire, the ground’s soil becomes hydrophobic – meaning it is unable to absorb water. This means debris and sediment is transported into larger bodies of water, resulting in the pollution of local supplies. Filtering such water sources is often costly and time-consuming.

2. Poor Air Quality

For example, if a forest burns, then large amounts of smoke are released into the atmosphere. This smoke includes microscopic particles – often less than 2.5 micrometers in diameter, or around one-seventieth the size of a human hair. These particles are so small that our bodies find it difficult to filter them out of our airways. Consequently, they get **lodged deep in our lungs**.



3. Serious Damage to Human Health

The World Health Organization (WHO) has highlighted how forest fires can have a major impact on **mortality and morbidity** depending on the size, speed, and proximity of the fire. The WHO says young children, pregnant women, and older adults are the most susceptible to “health impacts” from smoke and ash. In addition, the WHO explains that smoke and ash from wildfires can greatly affect "those with pre-existing respiratory diseases or heart disease." Meanwhile, as well as fatalities, wildfires can cause burns, decreased lung function, pulmonary inflammation, bronchitis, exacerbation of asthma, and exacerbation of cardiovascular diseases, such as heart failure.

How You Can Reduce Solar Farm Fire Risk

Given that fires at solar farms pose significant danger to environmental and human health, solar farm operators must do all they can to protect their renewables from fire risk. There are a few ways to stay safe from fire in addition to integrating fire suppression systems and fire risk assessments.

- Make certain independent third parties regularly test solar systems
- Integrate additional safety components at your solar panel farm
- Establish standardized quality assurance measures

- Replace defective or prematurely aged components

With the challenges of the solar supply chain and current solar prices, it's important to take action and prevent the worst-case scenario from occurring.

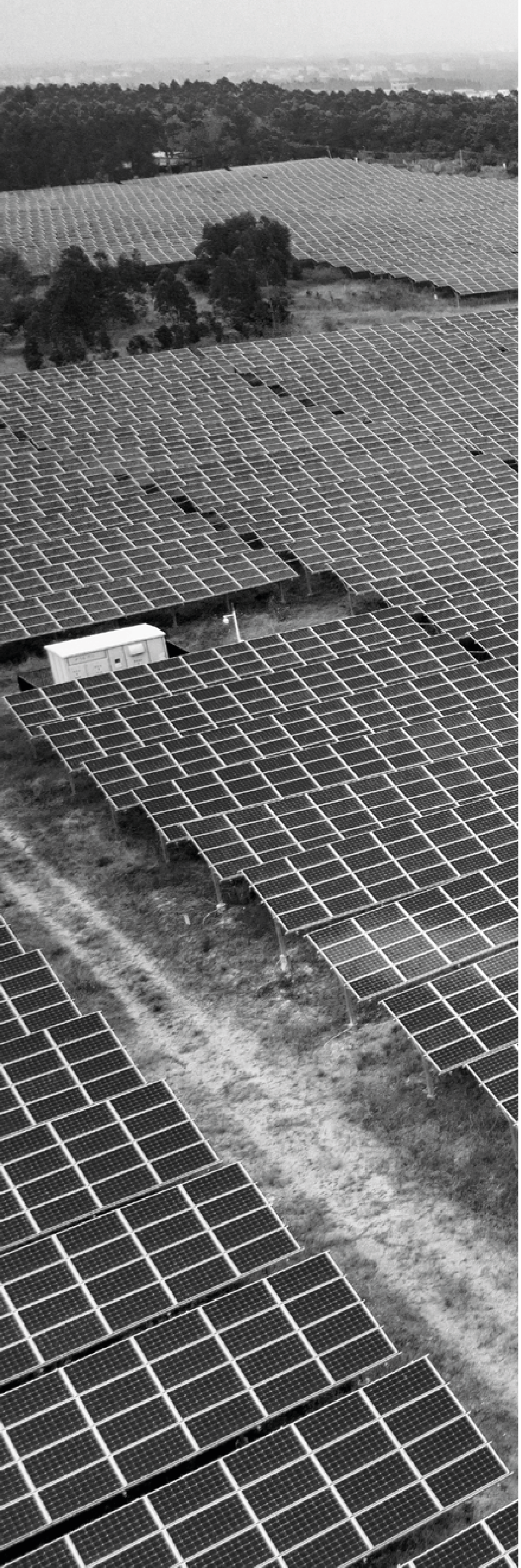
Exhibit 9

FIRETRACE International

Halma

HIDDEN DANGER

Why solar farm fire risk could be greater than you think



Summary

The solar industry is potentially underestimating the risk of fire at solar farms.

Why? It's partly because there is a shortage of data on solar farm fires, and partly because research into the issue has given rise to suspicions that fires at solar farms have been under-reported.

This report will look at the solar fire data that is available and analyse what conclusions can be drawn from that data.

In addition, the report will look at:

- The factors that make a fire at a solar farm more likely
- The possible root causes of solar-related fires, and
- The PV components most likely to cause solar farm fires

Finally, the report will also explore what steps you can take to reduce the risk of solar farm fires.

What is certain is that solar farm fire risk is an issue that the solar industry needs to take more seriously. This is particularly the case when you consider how rapidly the global solar industry is expanding.

Data from the International Energy Agency (IEA) – which was published in the IEA Photovoltaic Power Systems Programme's 'Snapshot of Global PV Markets 2022' report – showed that the world's total cumulative installed PV capacity increased 23% in 2021 to 942GW.[1]

With the number of solar installations growing fast – amid concerns that instances of solar fires are being under-reported – now is the time for action to be taken to minimize solar farm fire risk.

1 https://iea-pvps.org/snapshot-reports/snapshot-2022/

How significant is solar fire risk?

There is a severe lack of data on the prevalence of solar farm fires.

Indeed, some studies have concluded that there is a high likelihood that instances of solar farm fires are under-reported.

A study by the UK's BRE National Solar Centre – which was entitled 'Fire and Solar PV Systems – Investigations and Evidence' and detailed an investigatigation into a total of 80 potential PV-related fire incidents – led to the finding that researchers "strongly suspect a degree of under-reporting, especially amongst solar farms and domestic thermal events that were resolved by a solar installer/maintenance engineer."[2]

With regard to the data that is actually available, the US Department of Energy's Solar Energy Technologies Office has cited a study conducted by European testing and certification company TÜV Rheinland – entitled 'Assessing Fire Risks in Photovoltaic Systems and Developing Safety Concepts for Risk Minimization' – which found that, in approximately half of 430 cases of fire or heat damage in PV systems, the PV system itself was considered the "cause or probable cause."[3]

Meanwhile, the study carried out by the BRE National Solar Centre found that more than a quarter of fires involving solar systems were caused by the photovoltaics and those fires were all "serious fires", meaning fires that were "difficult to extinguish and spread beyond the area of origin."

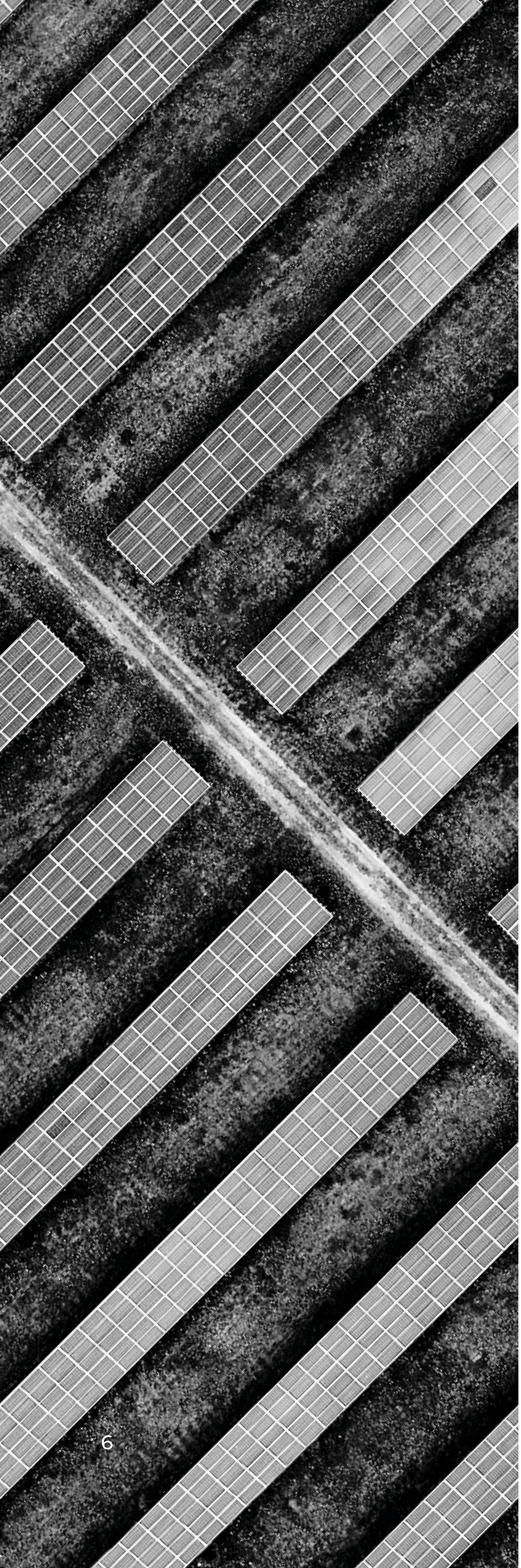
2 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/786882/Fires_and_solar_PV_systems-Investigations_Evidence_Issue_2.9.pdf

3 https://www.energy.gov/sites/default/files/2018/10/f56/PV%20Fire%20Safety%20Fire%20Guideline_Translation_V04%2020180614_FINAL.pdf

However, as already indicated, the BRE National Solar Centre study did emphasize that the full extent of solar fire risk may have been concealed. Specifically, it highlighted how, in one instance during the course of the study, researchers were “denied access to one site by the insurance company’s loss adjuster.”

As a result, we cannot rule out the possibility that solar farm fire risk, and occurrences of solar farm fires, may be more prevalent than the available data suggests.

There is a high likelihood that instances of solar farm fires are under-reported.



What statistics are available?

Despite the challenges in obtaining data that provides a comprehensive picture of the extent of solar fires and the prevalence of solar fire risks, there are a number of studies that have attempted to gain an insight into the issue.

For example, one data set released by the US Fire Administration (USFA) found that instances of solar system fires more than doubled during the period 2015 to 2018.

The USFA reportedly does not track fires from solar installations, instead filing them under the 'other' category for causes. In the aforementioned instance, the USFA data was only made available following a specific request from an executive at a solar maintenance company.

The USFA data that was obtained showed that there were 56 solar system fires recorded in 2018, up from 25 in 2015.[4] A third of the fires that were recorded by USFA during the period 2015 to 2018 occurred in California, Arizona and Nevada.

However, while the number of fires recorded by the USFA more than doubled between 2015 and 2018, the number of solar installations in the US increased at a similar rate during the same period – from less than 30,000MWdc to more than 60,000MWdc, according to Solar Energy Industries Association research data – which suggests solar fire risk may not actually be increasing.[5]

Yet, in contrast, data from Australia indicates that the opposite is true – that is, solar fire risk is, in fact, increasing exponentially.

Statistics from the Australian PV Institute show that PV installations in the country increased from around 7.3GW in January 2018 to more than 20.7GW in December 2020.[6] However, while the increase in PV installations in Australia during the period was less than three-fold, data from Fire and Rescue New South Wales (NSW) showed that there was a six-fold increase in the number of solar fires attended by firefighters in the period 2018 to 2020, according to reports.[7] In 2020, Fire and Rescue (NSW) attended 139 solar fires, compared to 22 in 2018.

4 https://onedrive.live.com/?authkey=%21ADZAYZw3zBKJ%5F1k&id=C8BE25A716873030%216383&cid=C8BE25A716873030

5 https://www.seia.org/solar-industry-research-data

6 https://pv-map.apvi.org.au/analyses

7 https://www.smh.com.au/national/nsw/the-irony-s-not-lost-on-me-solar-panel-safety-device-led-to-500-per-cent-rise-in-rooftop-fires-20210129-p56xtp.html

What are the risk factors?

There are three possible root causes for solar farm fires, according to the BRE National Solar Study Report.

They are:

- an error in the system design
- a faulty product (a design or quality issue)
- poor installation practice

The report said DC isolators were found to present the greatest fire risk. Around 30 percent of the incidents recorded in the study were caused by DC isolator malfunctions.

A number of the incidents in question involved ingress of water into DC isolators, all with upward-facing cable glands, the BRE study said. The study also concluded that there was evidence of fires originating within DC isolators with “poor contact design” – that is, originally being designed for AC operation and being re-designated as DC-rated by the manufacturer – and with incorrect internal wiring.

The BRE report said there were three separate issues with DC isolators:

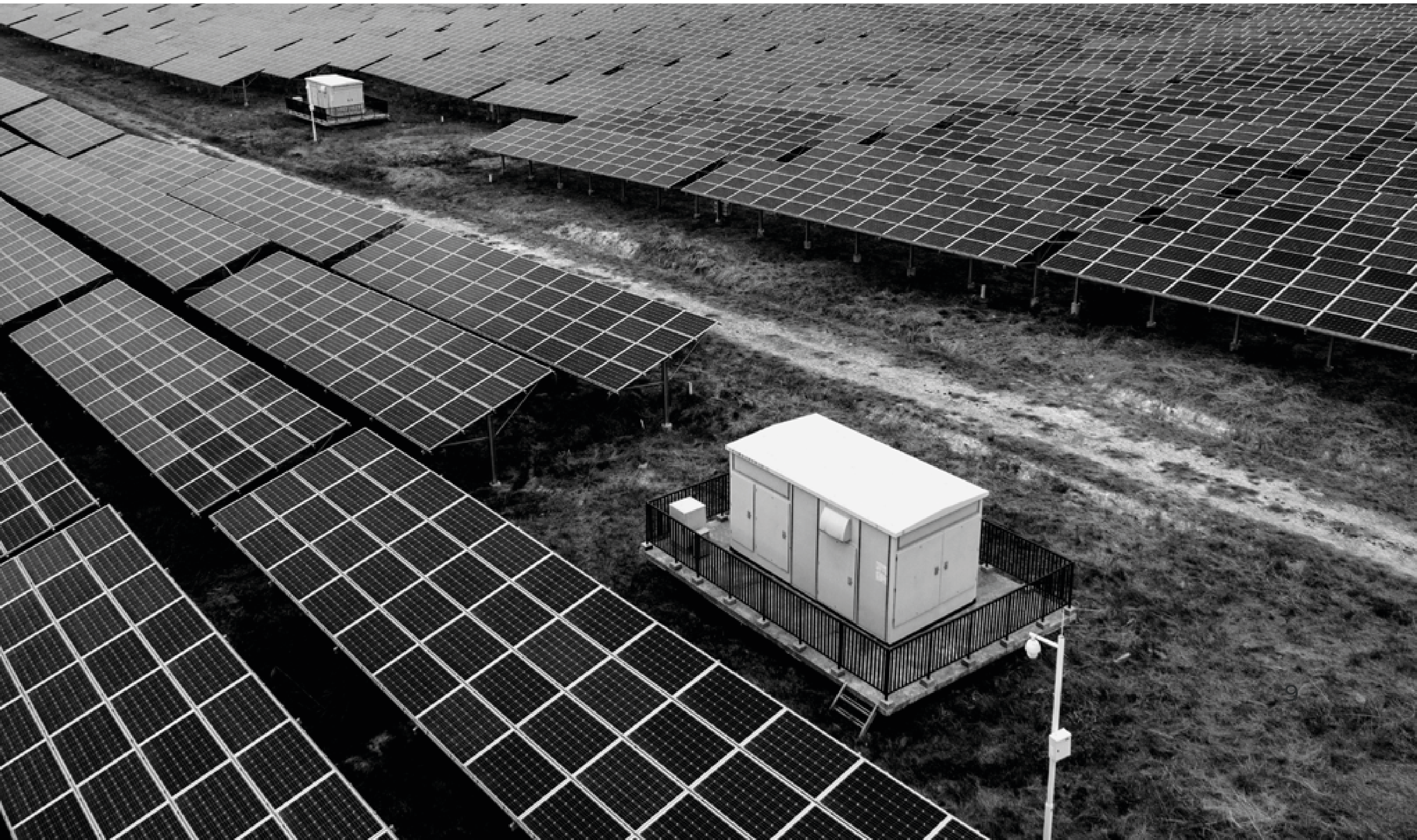
1. **Poorly designed or constructed products**
   Models originally designed for AC are “unlikely to be reliable over the life of a PV system.”
2. **Incorrectly specified DC isolators**
   Isolators that are underrated for the current or voltage of the PV strings connected, for example.
3. **Poor installation practice**
   The BRE report said this category accounted for the “majority of DC isolator failures leading to fires or thermal events.” Poor installation frequently caused ingress of water into the isolator casing causing arcing.

Meanwhile, DC connectors are the second most likely PV component to cause a fire.

DC circuits connect the PV modules together, increasing the voltage in a similar way to connecting batteries in series. Parallel strings of PV modules increase the current. The DC circuits are fed back to the inverter, sometimes via a DC isolator.

The metal contacts of DC connectors tend to remain connected by frictional forces, even when the supporting plastic body has been burnt off, the BRE report said. Therefore, any DC connectors that have been subject to arcing should be suspected as a likely source of ignition.

DC isolators were found to present the greatest fire risk.



Inverters: How they cause fires

A number of fires start in inverters, which form the most complex part of a PV system and manage the power that flows through them. Though they have sensors and other safety features, there have been incidents of solar fires logged as initiating in an inverter, according to the BRE report.

The BRE has also highlighted how the use of "faulty inverters" has resulted in solar-related fires.[8] In 2020, there were reports of firefighters called to extinguish a fire in the central inverters of the Ullum photovolataic park – owned by energy company Genneia – in Argentina. In this incident, a number of inverters had caught fire, with firefighters taking an hour and a half to extinguish the blaze.[9]

Meanwhile, an article published by the Solar Power World website highlighted how "electrical abuse" was one of "three main abuse factors" that can send a battery into thermal runaway [meaning a situation where the heat generated within a battery exceeds the amount of heat that is dissipated to its surroundings]. The article added: "Electrical abuse happens during overcharging, undercharging or shorts from the inverter."[10]

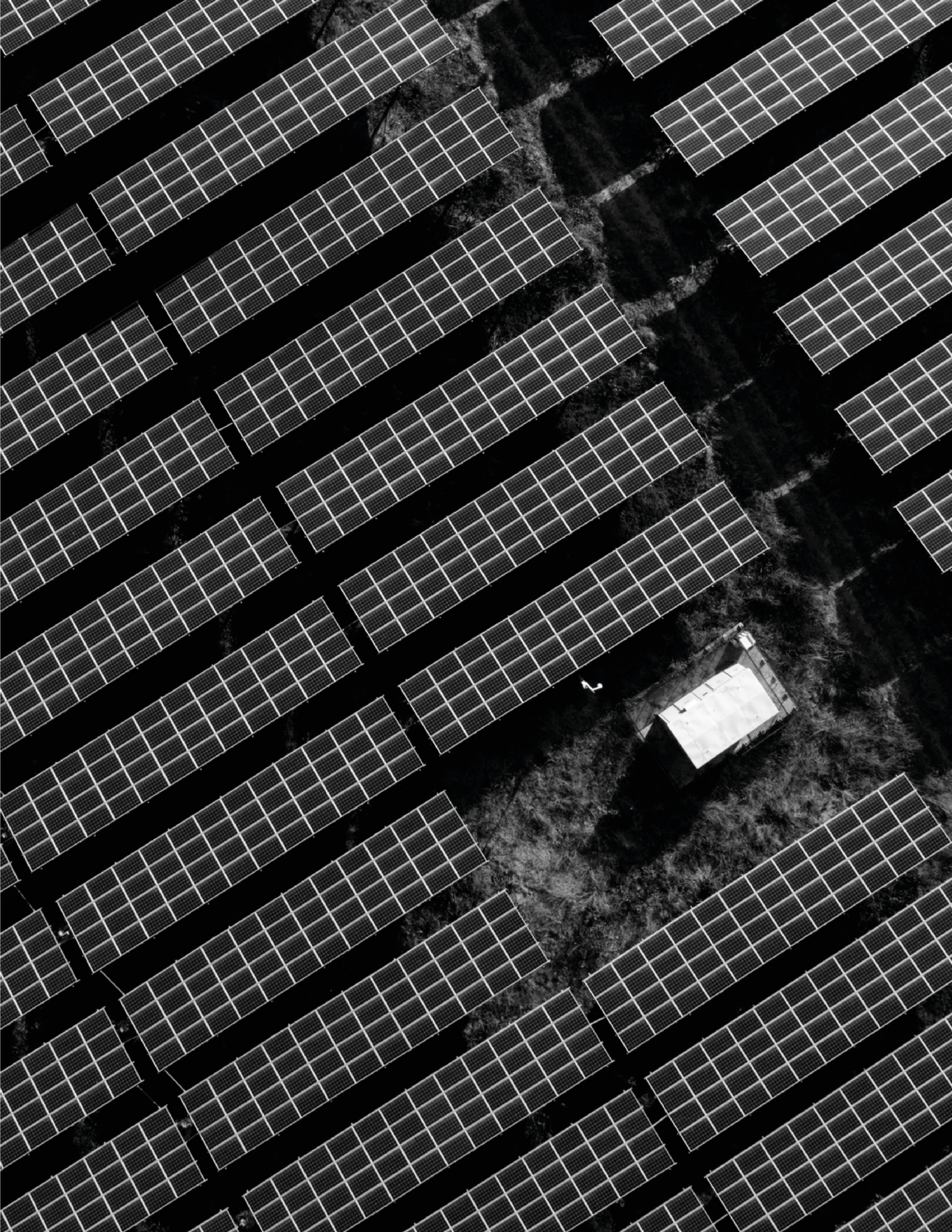
What causes fires in inverters? According to photovoltaic system distributor Solarity, inverters are combustible due to their polymer content.[11] Solarity has also highlighted how, during and after a solar fire, the PV system can potentially produce liquid, solid or smoke emissions and firefighters responding to the incident "could be exposed with dangerous levels of metals such as lead (c-Si) or cadmium and selenium."

8 https://www.bre.co.uk/page.jsp?id=3211

9 https://www.pv-magazine.com/2020/10/21/fire-accident-at-argentinian-solar-parks-central-inverters/

10 https://www.solarpowerworldonline.com/2020/02/just-how-concerned-should-the-solar-industry-be-about-battery-fires/

11 https://solarity.cz/blog/fire-hazards-and-mitigation-in-photovoltaic-systems/#



How can the risk of solar fires be reduced?

Even if quality assurance measures have been implemented for solar systems, it is difficult to completely eradicate the risk of fire.

The TÜV Rheinland study concluded that "despite quality assurance measures, overheating or electric arcs cannot be ruled out 100%."

So what steps can be taken to minimise the risk of solar farm fires?

Recommendations made in the TÜV Rheinland study included:

1. **Ensure solar systems are regularly tested by independent third parties**
2. **Incorporate additional safety components everywhere possible**
3. **Create standardized quality assurance measures**
4. **Ensure defective or prematurely aged components are promptly replaced**

The report added that electric arc detectors can also reduce risks. However, it also said that it was vital that the electric arc detector remains fully functional over a very long period of time, if possible during the entire service life of the PV system, without itself causing any faults in the system. The report continued: “Protective measures such as an integrated self-test could be helpful here.”

In addition, an electric arc detector is “moreover useful only if it can be assumed to reliably detect electric arcs”, the TÜV Rheinland report concluded.

It added: “Electric arcs in modules produce different noise patterns than those in serial terminals. Different cable lengths greatly differ in their dampening of electric arc signatures. Interference from inverters, switching transients, or coupled radio signals can mask or overlay the noise coming from the electric arc. Only very robust detection algorithms tested on different systems can ensure real added utility here.”

Solar farm operators could also consider addressing the issue of fire risk by incorporating fire suppression systems, for example.

Conclusion

The risk of fires at solar farms is potentially being underestimated due to under-reporting and a lack of available data.

However, a number of studies have indicated that solar fires are on the increase. One US study found that solar system fires had tripled over a three-year period, while data from Australia showed that there had been a six-fold increase in the period 2018 to 2020.

Hence, there is an urgent need for the solar industry to address the issue of fire risk, particularly with data showing that global cumulative installed PV capacity increased by around a quarter in 2021.

Studies have shown that there are three root causes for photovoltaic fires – they are: an error in the system design; a faulty product (a design or quality issue); or poor installation practice.

The photovoltaic component that presents the greatest fire risk are DC isolators, which cause around a third of solar fire incidents.

However, DC connectors and inverters can also pose significant fire risks.

It's difficult to completely eradicate the risk of fire at solar farms, but there are a number of key steps you can take to minimize the risk.

These steps include having solar systems regularly tested by independent third parties and incorporating additional safety components, such as fire suppression systems.

With the number of PV installations dramatically increasing around the world, taking these steps will be vital in order to reduce fire risk.

Would you like to talk about the risks in this report? How about your approach to fire risk in your portfolio?

Get in touch with the Firetrace team today.

www.firetrace.com/contact

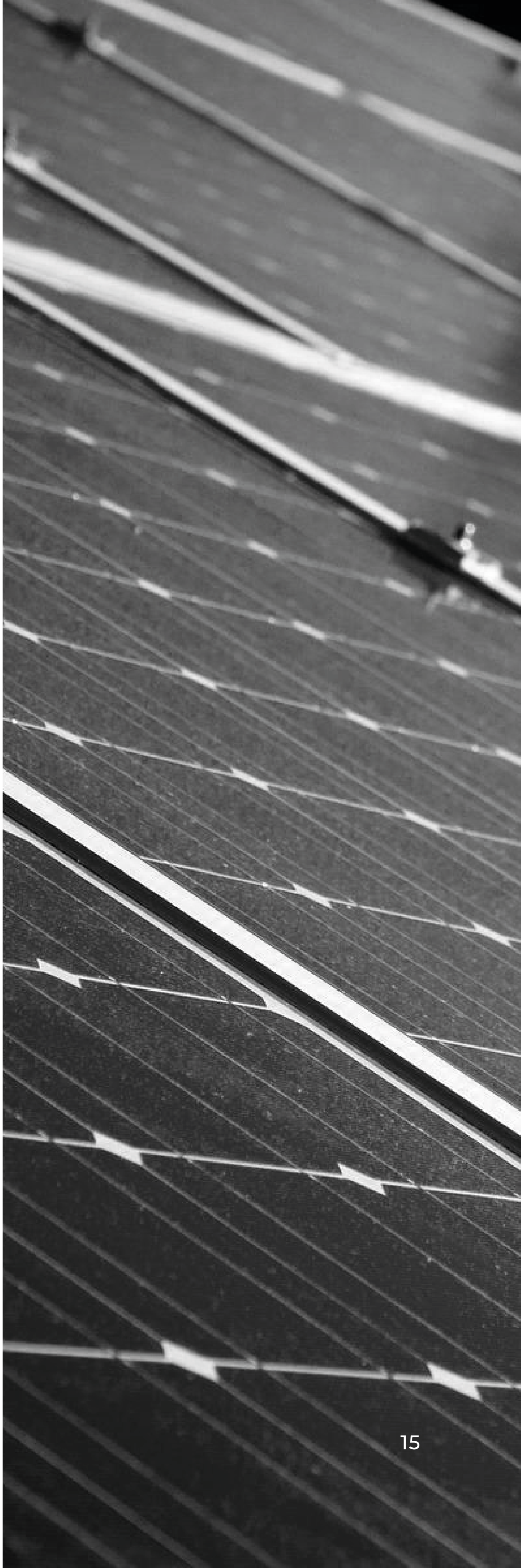


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Exhibit 10

HEARING OFFICER MEETING
DECEMBER 4, 2024
CASE NO. 24-5200
RANCHO VIEJO LIMITED PARTNERSHIP
RANCHO VIEJO SOLAR, LLC
AES CLEAN ENERGY DEVELOPMENT, LLC
Jointly the APPLICANT
CONDITIONAL USE PERMIT

RECOMMENDED ORDER

THIS MATTER came before the Sustainable Land Development Code ("SLDC") Hearing Officer for hearing on December 4, 2024, on the request of the above-referenced Applicant for a conditional use permit ("CUP") to allow a 96-megawatt solar facility ("Project") on approximately 684 acres ("Site") in Sections 2-9, Township 15 North, Range 9 East that is zoned Rural Fringe (RUR-F) and is accessed from NM State Highway 14 in Commission District 5.

The requirements of the SLDC used to process the Application:

- Chapter 4.9.6 Conditional Use Permits
- Appendix B – Use Matrix

Two organizations that registered pursuant to Chapter 2.2.3 of the SLDC intervened this case: Clean Energy Coalition for Santa Fe County and the San Marcos Association.

The Hearing Officer, having reviewed the Application, the testimony and exhibits from the hearing including the County's Staff report, as defined below, recommends the Application be denied and makes the following Findings of Fact and Conclusions of Law.

I. THE APPLICATION

1. The Applicant states that it seeks a CUP to build and operate the Project, which would be located on privately-owned property approximately three miles south of Santa Fe city limits, to include the following: a 680-acre solar facility; a one-acre collector substation; a three-acre battery energy storage system ("BESS"); a 2.3 mile tie-in line; a 2.1-mile access road; a 26.3-foot diameter

Exhibit 10

by 7.2-foot above ground water storage tank; and a 1,400 square foot operations building . (Ex. B 1-1)

2. The Applicant states the Project would generate 96 megawatts (MW) and would include 48 MW of four-hour duration BESS for storage and delivery of solar energy intended to replace part of the fossil fuel portfolio of the Public Service Company of New Mexico ("PNM"). (*id.*)

3. The Applicant submitted studies, reports, and assessments as specified in the Technical Advisory Committee ("TAC") letter dated March 23, 2022, and the Applicant lists these in the CUP application. (Ex. B 2-5; Ex. E)

4. The Applicant addresses the specific criteria of Chapter 4.9.6.5 of the SLDC for a CUP as follows:

i. *will not be detrimental to the health, safety and general welfare of the area*

The Applicant states that the Project is a static, non-obtrusive land use that will be compatible with surrounding land uses, because solar projects do not create significant noise, light, traffic, or other operational impacts. (Ex. B 2-6)

ii. *tend to create congestion in roads*

The Applicant states that the Project will have higher traffic volume during the 12-month construction period but will have very low traffic once it is operational. The Applicant explains that access to the Site is from an existing gated access point on NM 14. (*id.*)

iii. *will not create a potential hazard for fire, panic, or other danger*

The Applicant states that it will comply with the most current applicable codes of the state, county and other entities and lists the rules and ordinances. *See* Ex. B 2-7 The Applicant states that is has been working with Santa Fe County Fire Department to " ... design and construct the [P]roject's access, circulation and emergency measures." (Ex. B 2-7)

iv. *tend to overcrowd land and cause undue concentration of population*

The Applicant states that the Project will not be detrimental to the use or development of adjacent land, because the Project is static, non-obtrusive, and will not overcrowd the land or cause undue concentration of population, nor will it change any existing population patterns. (*id.*)

v. *interfere with adequate provisions for schools, parks, water, sewerage, transportation or other public requirements, conveniences or improvements*

The Applicant states that compared to permitted uses in the RUR-F zoning district, the Project will provide a net positive impact to the County's services. The Applicant maintains that the Project will not require a significant long-term water supply although during the construction period, approximately 100 to 150 acre-feet will be delivered to the Site by water trucks from the County's bulk water station commercial pipe water, Ranchland Utility Company Class A reclaimed water, County reclaimed water, or any other legally permitted commercial water sources. The Applicant estimates the Project's long-term water use will be two to three acre-feet per year for solar panel washing and potable water for the operations building. The Applicant states that portable toilets will be used during construction, and a septic tank will be constructed for the operations building. (Ex. B 2-7, 2-8)

vi. *interfere with adequate light and air*

The Applicant states that any required lighting will comply with the SLDC and the County's night sky ordinance. The Applicant anticipates that the only air impact would be short-term emissions from equipment use and the dust from road travel during the construction period and maintenance phase. (Ex. B 2-8)

vii. *be inconsistent with the purposes of the property's zoning classification or in any other way inconsistent with the spirit and intent of the SLDC or SGMP* [Sustainable Growth Management Plan]

The Applicant responds by quoting the SLDC's definition for the RUR-F and stating that "… commercial solar energy production facilities are permitted within the RUR-F zoning district only after review and approval of a Conditional Use Permit." (*id.*)

5. The Applicant addresses the relevant Sustainable Design Standards set forth in Chapter 7 of the SLDC that are applicable to all development. (Ex. B 3-1 through 3-7)

Sections 7.2 and 7.5 - The Applicant states that the Project will have higher traffic volume during the construction period but will have very low traffic once it is operational. (Ex. B 2-6) The Applicant states that the Project has been designed to comply and conform with state and county fire codes. The Applicant states that it is working with third parties to provide safety and fire management training for fire departments located within the vicinity of the Project, and that this training will occur prior to the completion and energization of the Project. The Applicant states that Hazard Mitigation Analysis ("HMA") has been prepared to include site and product specific fire risk assessment and a first responder plan and that local responders will have access to these reports. The Applicant maintains that no special materials are required to respond to a fire event for the containerized BESS units as only standard water application to the adjacent BESS containers is required, and this is necessary only in the case where all internal fire suppression systems have failed. The Applicant continues to explain that if a battery fire occurs, the enclosures would release fire suppressant in large concentration directly into the cell which would remove heat and prevent thermal runaway throughout the enclosure. The Applicant claims that the UL 9540a tests of this system indicate adequate prevention of thermal runaway, and the AES Energy Storage solution will achieve UL 9540 certification prior to the Project's commercial operation. (Ex.B 3-2)

Sections 7.6; 7.7; 7.8; 7.9; 7.10 – The Site will have a minimum 1,000-foot setback from any adjacent property line. The solar project perimeter will be enclosed by an 'agricultural style' fence with posts between 8 and 12 feet tall. The collector substation and BESS may be enclosed by a chain-link fence. The Applicant anticipates a motion sensor and downcast shaded security lighting at the access gate, battery storage and substation location operations building, and solar pads – all of which will comply with county lighting ordinances. A small identification sign may be posted at the entry gate to the Project. The Applicant describes the parking at the Site and explains that work on the 2.3 mile generation tie-in line ("gen-tie") may occur at night to minimize outages. (*id.*)

Sections 7.11; 7.12; 7.13; 7.14; 7.15 - The Applicant describes the internal roads at the Site and states that the operational electrical needs will be provided from the Project substation. The Applicant states that the long term water use following construction will be two to three acre-feet a year of water stored in the 5,000-gallon potable water tank; portable toilets will be used during construction, and a septic tank will be constructed for the operations building. The Applicant states that once the Project is operational, it will produce energy seven days a week. As the Project is to be located on property that is zoned RUR-F, it is outside the designated open space areas. (Ex. B 3-3)

Section 7.16 - The Applicant reviewed the steps it has taken to comply with the Historic Preservation Division of the Department of Cultural Affairs Department's regulations. (Ex. B 3-4; Ex P)

Sections 7.17; 7.18; 7.20 - The Applicant describes the measures it proposes to control runoff and reduce erosion at the Site. The Applicant references the Hydrologic and Hydraulic Study it had performed for the Project and notes that other than 0.5 acre of the proposed gen-tie corridor, the Project avoids the Zone A floodplain. The Applicant states that the solid waste generated during construction will be hauled away by a private contractor to a licensed waste management facility. (Ex. B 3-4, 3-5)

Section 7.21 - The Applicant describes the efforts it will make to suppress emission and air pollutants during construction and notes that an air quality permit is not required. The Applicant notes that similar emissions would occur during the decommissioning of the Project. The Applicant acknowledges that there will be a temporary increase in ambient noise levels during construction, but this increase will dissipate within approximately 0.15 to 1.2 miles of the Project area. The Applicant maintains that once the Project is operational, it will have a negligible effect on ambient noise levels beyond the immediate vicinity and refers to the Noise Technical Report for a detailed analysis prepared by SWCA Environmental Consultants ("SWCA") submitted with the CUP. (Ex. B 3-5, 3-6)

Section - 7.22 The Applicant submitted the Rancho Viejo Solar Project Decommissioning Plan prepared by SWCA that indicates a lifespan of the Project of 25 to 35 years if properly maintained. This Plan estimates approximately $8.9 million in decommissioning expenses, and Applicant will provide such a commitment prior to final plat recording and permit approval and issuance. (Ex. B 3-6)

Section 7.26 - The Applicant explains that any easements required will be surveyed, executed, and recorded by separate instrument. (*id.*)

II. THE STAFF REPORT

6. At the hearing, Staff summarized the Staff report, which was submitted as part of the record. The written Staff report, including exhibits, attachments, and the oral summary is collectively referred to as the Staff Report ("SR").

7. Staff explain that the Applicant's request for a CUP is necessary pursuant to Chapter 4.9.6.1 and the Use Matrix of the SLDC as certain land uses are not permitted in zoning districts as a matter of right, but with appropriate standards and factors, may be permitted by the issuance of a CUP. Staff confirms that the Site is zoned RUR-F in which a commercial solar energy production facility is a conditional use. (SR 2)

8. Staff explain that any development must also comply with the following: the submittal of the required studies, reports and assessments of Table 6-1 of Chapter 6 of the SLDC, and the applicable design standards of Chapter 7. Staff comment as follows on the Application:

Section 6.6 (Traffic Impact); Sections 7.4 and 7.11 (Access and Road Design)

Staff state that the existing access point for the Project off of Highway 14, approximately 350 feet north of the Turquoise Trail Charter School, does not require additional public road construction, but the Applicant must comply with the specific requirements of the New Mexico Department of Transportation's access permit issued on May 31, 2023. (SR 2-3)

Sections 6.5 and 7.13 (Water Supply and Water Conservation

Staff restate the Applicant's projected water use and water sources and notes that the Application does not address a passive water harvesting system, which is required by Section 7.13.11.7.3.b.iv and will be required of the Applicant. (SR 3-4)

Sections 6.3 (EIR); 6.4 (APFA); and 6.7 FIA

Staff state that the Environmental Impact Report was submitted and reviewed by Glorieta Geoscience, Inc. (Ex. J). The Applicant submitted the Adequate Pubic Facilities and Services Assessment, but a Fiscal Impact Assessment was not required. (SR 5)

Section 7.5 (Fire Protection)

Staff state that the Site will include 20-foot-wide internal roads with fire lanes, minimum inside turning radii of 28-feet, gates equipped with emergency opening systems, and a 30,000 gallon above ground water storage tank for fire protection. Staff state that a Preliminary Hazard Mitigation Analysis has been prepared for the Project, and a final analysis will be done as part of he detailed engineering process, which will include site and product specific fire risk assessment and first responder plan. Local first responders will have access to these reports, and the Applicant will provide on-site, in-person training to local responders prior to commercial operation of the Project. Staff state that no special materials are required to respond to a fire event for the containerized BESS units, and only standard water application to the adjacent BESS containers is required and only after internal fire suppression systems fail. Staff repeat the Applicant's assertion that in the event of a battery fire, the enclosures would release fire suppressant in large concentrations directly into the initiating cell thereby removing heat and preventing thermal runaway throughout the enclosure. Staff state that the Applicant will provide UL 9540 certification for this specific system indicating adequate prevention of thermal runaway prior to the Project's commercial operation. Staff state that the Application was sent to the Santa Fe County Fire Department in addition to third party reviewer Atar Fire, and both entities have concluded that a sufficient level of information has been provided to validate the issuance of a CUP. (SR 5-6)

Section 7.6 (Landscaping)

Staff state that no new landscaping is proposed for the Project. (SR 6)

Section 7.7 (Fences)

Staff state the Applicant proposes to enclose the perimeter of the solar project with a maximum 8-foot-tall fence, and the on-site collector substation and BESS will 'more likely be' enclosed by a maximum 8-foot-tall chain-link fence. (*id.*)

Section 7.8 (Lighting); Section 7.9 (Signs)

Staff state that there will be motion sensor, downcast shaded security lighting at the access gate, battery storage and substation location, operations building, and solar pads.

Staff state that the Applicant proposes a small facility identification sign to be posted at the Project entry gate. (SR 7-10)

Section 7.10 (Parking and Loading)

Staff state that during operations, employee and visitor parking will be at the operations building and any loading activities would generally occur between 7:00 a.m. and 7:00 p.m. (SR 10-12)

Section 7.15 (Open Space)

Staff explain that as the project is located on property that is zoned RUR-F, it is outside the designated open space areas; but of the 828-tract, approximately 340 acres will remain as natural open space although some of that acreage will be within the 680-acre solar facility. (SR 12)

Section 7.16 (Protection of Historic Resources)

Staff state that with the avoidance of two undetermined resources, there will be no effect to any historic resources, *see* Exhibit P. (SR 12-13)

Section 7.17 (Terrain Management); Section 7.18 (Flood Control)

Staff state that during construction a Storm Water Pollution Prevention (SWPPP) will be developed and implemented to meet NMED's discharge permit requirements. Staff explain that a Hydrologic and Hydraulic Study indicates three arroyos flow from east to west through the Site, and the Project design has been refined to avoid placement of solar arrays within the arroyos. (SR 13)

Section 7.20 (Solid Waste)

Staff state that the Applicant will have solid waste generated during construction removed by a private contractor and transported to a licensed waste management facility; solid waste generated during the Project operation, projected to be minimal, will be disposed of at a licensed waste management facility. Staff state that the Applicant estimates a 30-year life for the Project at which time the Project will be decommissioned and the materials removed. (*id.*)

Section 7.21 (Air Quality and Noise)

Staff describe the actions the Applicant proposes to take during the 12-month construction period to reduce dust emissions. Staff state the Applicant anticipates only minimal, short-term emissions during the operations and maintenance phase, and decommissioning emission are expected to be similar to those emitted during construction.

As to noise, Staff explain that the Project is in a semi-rural area with low existing noise levels. Staff state that there will be a temporary increase in ambient noise levels during the construction period, which level will dissipate within 0.15 to 1.2 miles of the Project area. Staff state that during the operational years, the Project will have a negligible effect on the ambient noise levels beyond the immediate vicinity of the Project. (SR 14-15)

9. Staff set forth the seven CUP approval criteria and conclude that the Applicant has satisfied the criteria.

i. *will not be detrimental to the health, safety and general welfare of the area*

Staff respond to the Applicant's statements regarding this criterion by stating that the Applicant will be required to comply with all applicable SLDC requirements as well as state and federal laws and all codes and standards as adopted in Santa Fe County. (SR 17)

ii. *tend to create congestion in roads*

Staff state that the Highway 14 gated access will be improved, and the site threshold analysis indicates additional traffic impact studies are not warranted either for the construction or operation period. (*id.*)

iii. *will not create a potential hazard for fire, panic, or other danger*

In response to this criterion, Staff recite the applicable codes relevant to this Project. *see* SR 18. Additionally, Staff refer to the 30,000-gallon on-site water tank, and explain that as the BESS containers will be equipped with internal fire suppression systems, only standard water application to adjacent BESS containers is required, and this would only be in the event that all internal fire suppression systems fail. Staff explain that all information required by first responders will be included in the first responder plan part of the final approved Hazard Mitigation Analysis, and the Applicant will provide one-site and in-person training to the local responders prior to commercial operation of the system. (SR 18-19)

iv. *tend to overcrowd land and cause undue concentration of population*

Staff note that the Site will have acres of natural open space. (SR 19)

v. *interfere with adequate provisions for schools, parks, water, sewerage, transportation or other public requirements, conveniences or improvements*

Staff state: "The proposed solar facility is in a remote area of Santa Fe County and will not interfere with adequate provisions for school, parks, water, sewerage, transportation or other public requirements." (SR 19)

vi. *interfere with adequate light and air*

Staff state that the Project includes minimal lighting mainly for security, battery storage and substation location, the operations building and solar pads; all lighting will be required to comply with the SLDC. The monopoles, which Staff recommend for their minimal visual impact, for the gen-tie line will be required to blend into the natural landscape and be non-reflective. (SR 20)

vii. *be inconsistent with the purposes of the property's zoning classification or in any other way inconsistent with the spirit and intent of the SLDC or SGMP*

Staff explain that a commercial solar energy production facility is allowed in the RUR-F zone with the approval of a CUP, and the SGMP explicitly supports the development and distribution of renewable energies at a regional scale. (SR 20)

10. Staff state that the Applicant made the required notice by publication, mailing, and posting. (SR 15; Ex R)

11. Staff recommend approval of the CUP based on the Application, subject to the following conditions:

i. Compliance with all Reviewing Agencies' comments.

ii. The drilling or use of individual and/or shared wells for this use on this property is prohibited.

iii. The Applicant shall provide proper buffering and screening by installing a paneled fence to a portion of the proposed 8' tall fence that will be located on the southwest portion of the property.

iv. Construction fencing will be required around all designated archeological sites to preserve the integrity of these areas.

v. Prior to the recordation of the CUP site development plan, the access road and internal roads shall be permitted through Santa Fe County, built out and inspected, or bonded for 125% of the construction cost.

vi. The CUP site development plan showing the site layout and any other conditions that may be imposed through the approval process shall be recorded at the expense of the Applicant in the office of the County Clerk in accordance with Chapter 4, Section 4.9.6.8.

vii. Utilization of the 70-foot-tall steel monopoles will be required, as they have less of a visual impact. The poles will be required to blend into the natural landscape and shall be non-reflective.

viii. A decommissioning bond (may contain salvage value) will be required prior to recordation of the CUP site development plan, and must be in place for the life of the project.

ix. Applicant will be required to apply for all applicable Development Permits after the CUP recordation.

x. Prior to the submittal of any applicable Development Permit the Applicant will be required to renew its access permit from NMDOT.

xi. Applicant shall obtain an approved liquid waste permit from NMED prior to the submittal for a Development Permit.

xii. The Applicant is required to work in consultation with the appropriate flood zone authorities to address the requirements specified in Chapter 7, Section 7.18.9.1 of the SLDC for any steel monopole located within a Zone A flood hazard area and submit the findings to staff for the record.

xiii. Construction activity to be limited to a Monday through Friday, 7 am to 7 pm work schedule. Any deviation from these construction hours will require 48 hours' notice to Santa Fe County and neighboring property owners.

xiv. Prior to operating the Applicant shall obtain a Santa Fe County Business License.

xv. The Applicant shall provide a detailed and accurate water budget for construction, operation and maintenance, and decommissioning. The water budget shall include water source and water trucking, and the water budget shall be reviewed by Glorieta Geoscience and approved by Santa Fe County Utilities.

(SR 21-22; Tr 27-28)

III. INTERVENORS

Clean Energy Coalition ("CEC")

12. CEC stated that it is an organization of 1,300 members, and it opposes the Application to site the Project amid three residential communities with approximately 10,000 homes, 25,000 residents, the Turquoise Trail Charter School and the state prison with 790 inmates. CEC presented three witnesses. (Tr 39-51)

13. CEC stated that the County does not have specific standards regulating utility-scale solar facilities that contain battery storage, and noted that about 300 counties across the country have enacted moratoriums on such facilities. (Tr 39)

14. CEC questioned Staff regarding air quality tests of emissions during operation of lithium battery facilities during operation, explosions and fire, and Staff responded that such air quality tests are not required for the CUP and are not addressed in the EIR. Atar Fire, the County's third-party fire expert, responded that lithium batteries do not give off emissions during normal operations and stated that tests following the fire at the Escondido, California facility developed by the Applicant indicated no detectable toxic gases outside the property line; the Otay Mesa fire, also in California but not at a facility designed or operated by the Applicant, which burned for eleven days, also reported no detectable amount of toxic gas emissions. (Tr. 31-32)

15. CEC questioned Staff on three fires at AES facilities: Surprise Arizona; Chandler, Arizona; and Escondido, California. Staff responded that it was aware of the fires, Atar Fire reviewed them as well, and determined that the battery systems used at those facilities represented an older design of such systems and were not the newer generation that is proposed for the Project. (Tr 36)

16. CEC's witness Kaye Cooper-Mead, an Eldorado resident, addressed the Project *vis a vis* the surrounding area and points out that there are residences as close at 500 feet from the

Project's boundaries, and the area is drought-prone with high winds predominantly blowing from west to east toward Eldorado with some homes reliant solely on well water from a shallow aquifer. (Tr 40)

17. Cooper-Mead stated that there have been three fires from battery energy storage systems in the last five years at the Applicant's facilities, and she believes there is potential for groundwater contamination at the proposed Site from the PFAS-laden fire suppressant. The Applicant responded that the PFAs for the cells proposed for this Project are not liquid, do not dissolve in water, and would not penetrate to groundwater. (Tr 41; 47)

18. Cooper-Mead questioned the effect the Project's proximity to the community on homeowner's insurance and whether such insurance would become unavailable. (*id.*)

19. Cooper-Mead pointed to the limited economic benefit, after the initial construction, to the County of only four to five jobs for the remainder of the facility's life of 35 years. (*id.*)

20. Cooper-Mead cited to Chapter 7 of the SGMP defines "utility-scale" as 300 kilowatts, or about one-third of a megawatt and that utility-scale generation facilities such as this Project with 570,000 lithium-ion battery cells are not allowed in the RUR-F zone in compliance with the goals of the SGMP. (Tr 42-43)

21. Randy Coleman, vice-president of CEC and resident of Eldorado testified that the proposed utility-scale solar and battery Project would be detrimental to the health, safety, and general welfare of the area and described the three fires in the Applicant's battery storage facilities since 2019, He testified that the fire at a facility in Surprise, Arizona is considered the most dangerous fire in the history of battery energy storage systems and resulted in the most serious injuries to first-responders. He stated that this facility had only 10,584 battery cells in one walk-in container as opposed to the 570,000 cells in 38 containers proposed for this Project. He described the 2022 fire in Chandler, Arizona at a 10 MW-facility with 3,200 lithium-ion batteries that created a hazmat situation forcing a quarter-mile evacuation and shelter in place order; reports stated this fire burned for two weeks, and the Applicant has still not released information to the public about the fire and its causes. He stated that the Escondido fire in a facility using BESS designed by the Applicant in September of 2024, forced evacuations in the area. (Tr 44)

22. Coleman stated that the Applicant has selected the least safe of six types of lithium-ion batteries and the ones most likely to result in thermal runaway fire burning the hottest and fastest. (*id.*)

23. Coleman testified that according to wildfirerisk.org, the Eldorado area has a high risk of wildfire, higher than 80 percent of the United States, and he provides the speed at which a wildfire could travel in winds of eight miles per hour as one mile in 26 minutes; if the wind speed were 16 miles an hour, it would cover a mile in 13 minutes. He describes a possible fire as affecting Rancho Viejo, San Marcos, Eldorado and perhaps even into the City of Santa Fe together with the toxic emissions and damage of PFAS groundwater contamination by efforts to suppress the fire. (Tr 45)

24. Lee Zlotoff, president of CEC and a resident of Eldorado, testified that he informed the County of a major natural gas pipeline that runs along the western border of Eldorado as the line emerges from the ground immediately adjacent to his property at a regulator station; he estimated the gas line is a mile from the proposed battery facility. He noted that the line does not appear in the Application. He testified that over 2,000-area homes are connected to that gas line, and in the event of the line rupturing or exploding, these homes could also be subject to explosion and fire. (Tr 48)

25. Zlotoff states that with over 500,000 lithium-ion batteries proposed for the Project there would be at least one if not multiple BESS fires over the course of the Project's 30-year life. (Tr 49)

San Marco Association ("SMA")

26. Dennis Kurtz, president of SMA, described the SMA as a registered organization that advocates for a large area from the Colibri Subdivision on the north to far below Madrid; from I-25 on the west to the borders of, but not including Eldorado or Galisteo, but including Cerrillos, Cerrillos Hills, and the western Galisteo Basin including Madrid. The SMA asks that the Application be denied. (Tr 51, 55)

27. Kurtz testified that the SLDC's CUP process does not apply to the Project as the Project is a huge electric power generating facility, *i.e.* a power plant, and is prohibited in the RUR-F zone. He points out that pursuant to the SGMP, any electric power generating facility greater

than 300,000 watts is considered utility scale, and this Project is 96 million watts. Kurtz continues by distinguishing between 'residential' and 'commercial' solar installation with the latter being something like an installation on a big box store. (Tr 52-54)

IV. PUBLIC COMMENT

28. At the December 4, 2024 hearing 35 attendees testified; six spoke in favor of the Application, and the 27 attendees stated their strong opposition to the Application. The pro-Application comments generally supported the development of more renewable energy generation and the increasing safety of solar production facilities. The comments from those opposed to the Application included the following: the size of the Project in an area surround by residential development, especially with the potential for fire, explosion, thermal runaway resulting in not just fire but wildfire; the increase of noise from such a large installation; the possible toxic gas emissions; the pollution of the shallow aquifer by fire suppressants needed in enormous quantities; the Applicant's history of fires and safety violations at its facilities across the country; the Applicant's choice of the older technology of lithium-ion battery storage rather than newer, safer technology such as iron air or flow batteries; and the possible negative effect on home values and difficulty, if not impossibility, of obtaining home insurance because of the proximity to a utility-scale solar generation and storage facility. (Tr 56-84)

29. Ashley Schannuaer, who resides one mile west from the Site in Eldorado, testified in opposition to the Application, and requested that his written testimony be admitted as an exhibit; there was no objection to its admission, and it is designated Hearing Exhibit AA. (Tr 66-67)

30. Schannuaer asserts his three primary points in opposition: i) the Project poses an unacceptable risk of fire, explosion, and toxic gases adjacent to residential land uses; ii) the Application is inconsistent with the spirit and intent of the SGMP; and iii) the Application violates Santa Fe County Ordinance 2023-09. (Ex. AA 3)

31. Schannuaer details the three fires (Surprise, Chandler, and Escondido) at facilities operated or designed by the Applicant, and notes that the Applicant's initial 2023 application to the County contained a Fire Risk Assessment that describes the physical reactions that may occur during a thermal runaway. (*id.* 6-11) Schannuaer continues by providing details of the 2021 Electric Power Research Institute's report on lithium-ion battery storage, which found that in a

four-year period, lithium-ion battery storage systems were the subject of at least 30 failures and destructive fires. (*id.* at 16)

32. Schannuaer states that the Applicant (AES Corporation) in its 2022 and 2023 Annual Reports filed with the U.S. Securities and Exchange Commission warned its investors of the inherent risks of its battery storage operations. (*id.* at 14)

33. Schannuaer's testimony provides extensive detail of the National Fire Protection Association's NFPA 855 Standard for the Installation of Stationary Energy Storage Systems and its 2022 Annex update titled "Guide for Suppression and Safety of Lithium-Ion Battery Energy Storage Systems." (*id.* 17-21)

34. Schannauer states that the County Commission updated its Fire Code by adopting Ordinance 2023-09 adopting the NFPA 855 including Annex G, but the County has not required the Applicant to comply with Ordinance No. 2023-09 even though another BESS project currently under review by the County, Linea Energy, is being required to do so. (*id.* 29-32)

35. Schannauer cites to Chapter 9 of the SGMP and quotes that "[t]he current emergency response system is not sufficient to service our population today." He also notes that the County has lacked an up-to-date emergency operations plan since 2008, and that an Emergency Management Task Force's 2023 report recommended development of an emergency operation plan for immediate attention. (*id.* 22-26)

36. Schannauer questions the viability of the Applicant's stated goal to sell the Project's output to the PNM, and explains that the Project does " … not appear to align with PNM's existing physical network and its resource and transmission plans." He states that the Project has been rejected at least twice from selection as part of the PNM power portfolio as its PNM's industrial load growth is occurring near Albuquerque, not Santa Fe. The Applicant responded that PNM's prior selection process is irrelevant to its future procurement. The Applicant stated this Project may or may not be selected by PNM, but the Applicant needs a commercial power purchase contract to finance and build the Project. (Ex. AA 53-55; Tr 66)

WRITTEN COMMENT

37. Prior to the submittal of the initial application in January 2023, and continuing with the subsequent Application, the County has received written comments regarding the Project, both in support and in opposition. These comments are available on the County website.

V. ANALYSIS

38. As several witnesses noted, the SLDC is intended to be consistent with the SGMP. *See* SLDC Chapter 1.4.1 Section 7.2.3.2 of the SGMP defines "utility scale" renewable energy generating facility as a facility generating more than 300 kW of electricity. Matrix B - Use Table of the SLDC lists under the "Utility" category of Uses "Gas or Electric Power Generation Facility" as a prohibited use in the RUR-F zone. The proposed Project is designed to generate 96 megawatts. The Applicant states that the Project could power the City of Santa Fe, which suggests that it would be classified as a utility-scale facility. However, the Application has been processed as a "commercial solar energy production facility," also listed under the "Utility" category but not including any size restriction on the generating capacity. The "commercial solar energy production facility" is a category that is allowed in the RUR-F zone as a conditional use and is an apparent carve out of the prohibition of electric power generating facilities in certain zones.

39. Chapter 4.9.6.1 of the SLDC provides that a CUP may be granted if the applicant satisfies each of the criterion set forth in that section. The County's grant of a CUP is discretionary, not mandatory, even though the criteria is met.

40. The Applicant, in this case, fails to satisfy the following criteria to be granted the requested CUP: *i) will not be detrimental to the health, safety and general welfare of the area; iii) will not create a potential hazard for fire, panic, or other danger; and vii) will not be inconsistent with the purposes of the property's zoning classification or in any other way inconsistent with the spirit and intent of the SLDC or SGMP.*

41. The Applicant's proposed Project contains a 3-acre BESS consisting of 570,000 lithium-ion batteries that as the Applicant itself stated " … the componentry in that system has not been deployed … [although] every component within that exact system has been deployed." Unrebutted testimony was presented that solar battery storage systems are evolving to ever safer forms, but the system proposed for this Project are of an older less safe type. (Tr 21, 23-24, 44)

42. Since 2019, there have been three large fires caused by lithium-ion batteries, some with injuries and involving evacuations, at solar facilities operated or designed by the Applicant; two of these fires occurred at facilities with significantly fewer battery cells, one with 3,200 cells and one with approximately 10,000 cells. The remote monitoring for this Project, which would be the only monitoring outside of the normal work week of onsite personnel, is located in Salt Lake City, Utah and is dependent on telecommunications capabilities. The potential for a catastrophic fire from failure of individual cells is vastly increased at a facility with over one-half million battery cells. (Tr 44)

43. The AES First Responder Mitigation Guidelines report, August 2024, states:

> The fire suppression system(s) at the BESS containers are designed to suppress small fires within the ancillary equipment and there is no expectation that a thermal runaway type fire within the battery banks will be suppressed. Thermal runaway produces explosive gases prior to ignition, and it is anticipated that early warning will be provided by the gas detection system within each container.
>
> Thermal runaway is one of the primary risks related to lithium-ion batteries. It is a phenomenon in which the lithium-ion cell enters an uncontrollable, self-heating state. Thermal runaway can result in: Ejection of gas, shrapnel, and/or particulates (violent cell venting) and extremely high temperatures.

(Guidelines 9-10)

44. The County does not have a hazardous material team/unit and utilizes the unit of the City of Santa Fe which is approximately 16 miles away from the Site. The closest County fire team is located off Hwy 14. Testimony about wildfire was provided using data from the National Wildfire Coordinating Group for grassy, juniper environment such as around the Project as follows: at a wind speed of eight miles an hour and low moisture conditions, a wildfire could be expected to cover one mile in 26 minutes; under the same conditions with a wind speed of 16 miles an hour, the fire would travel that mile in 13 minutes. (Tr 45)

45. The consequences of a fire from the Project could be catastrophic because of its proximity to the surrounding communities of Eldorado, Rancho San Marcos, and Rancho Viejo - an area with an estimated 10,000 homes and approximately 25,000 residents. Staff stated that the Site is approximately 550 feet from the Rancho San Marcos subdivision and 4,000 feet from Eldorado. (SR 2)

46. Among other concerns expressed regarding the Project were fears of groundwater contamination from the fire suppressants. In the event of a fire escaping from enclosed cells, there would be potential for PFAS-laden fire suppressant together with massive amounts of water used to extinguish the fire could contaminate the groundwater in areas with a shallow aquifer and residents reliant on domestic wells. (Tr 41)

47. Residents of the surrounding communities, all zoned rural residential, expressed fear that the Project would negatively affect their home values and ability to obtain reasonable home insurance, if such insurance would be available at any cost. The Applicant provided market studies to support its position that the siting of the Project would not negatively affect home values. The comparable properties were located in the vicinity of much smaller solar generation and battery storage facilities, 10 to 20 megawatts. Of the three properties near such facilities of approximately 100 megawatts, one was sited in an industrial area and the other was neighboring an asphalt facility. (Tr 15)

48. At the hearing when asked if there was any commercial or industrial facility in the County that posed a comparable degree of hazard as the proposed Project, Staff responded that it was not aware of any past, present, or future projects that posed such hazard as the proposed Project. (Tr 29)

49. The scale of the Project, over 200,000 panels and 570,000 lithium-ion batteries, together with the proximity to residential communities with homes as close at 500 feet from the Site boundary creates an unreasonable risk to the safety and welfare of the communities. This risk is compounded by the distance of these areas from County fire fighting stations, none of which has a hazardous material team.

50. The evidence indicates the Project would be detrimental to the health, safety and general welfare of the area; the Project would create a potential hazard for fire, panic, or other danger; and the Project is inconsistent with the purposes of the property's zoning classification and inconsistent with the spirit and intent of the SLDC and SGMP.

51. The evidence supports denial of the Application.

WHEREFORE, the Hearing Officer recommends that the Application be denied.

Respectfully Submitted

MARILYN S. HEBERT
Hearing Officer

Date: 23 December 2024

COUNTY OF SANTA FE)
STATE OF NEW MEXICO) ss

SLDC HEARING OFFICER O
PAGES: 18

I Hereby Certify That This Instrument Was Filed for Record On The 23RD Day Of December, 2024 at 11:54:52 AM And Was Duly Recorded as Instrument # **2049479** Of The Records Of Santa Fe County

Witness My Hand And Seal Of Office
Katharine E. Clar
Deputy ______________ County Clerk, Santa Fe, NM

Exhibit 11

Kirkland Appraisals, LLC

Richard C. Kirkland, Jr., MAI
9408 Northfield Court
Raleigh, North Carolina 27603
Phone (919) 414-8142
rkirkland2@gmail.com
www.kirklandappraisals.com

February 13, 2023

Jonathan W. Moore
The AES Corporation
282 Century Pl #2000
Louisville, CO 80027

RE: Rancho Viejo Solar Impact Study, near Santa Fe, Santa Fe County, New Mexico

Mr. Moore

At your request, we have considered the impact of a proposed 96 MW with a 48 MWAC Battery Energy Storage System (BESS) solar farm proposed to be constructed on approximately 758.96 acres of a parent tract with 8,225 acres off NM 14 Highway, near Santa Fe, Santa Fe County, New Mexico. Specifically, I have been asked to give my professional opinion on whether the proposed solar will or will not be injurious to or diminish the use, value and enjoyment of other property in the immediate vicinity for the purposes already permitted as well as whether or not it will impede the normal and orderly development and improvements of surrounding property for uses permitted by right in the zoning districts of surrounding property.

To form an opinion on these issues, we have researched and visited existing and proposed solar farms in New Mexico as well as other states, researched articles through the Appraisal Institute and other studies, and discussed the likely impact with other real estate professionals. We have not been asked to assign any value to any specific property.

This letter is a limited report of a real property appraisal consulting assignment and subject to the limiting conditions attached to this letter. My client is The AES Corporation represented to me by Jonathan W. Moore. My findings support the application. The effective date of this consultation is February 13, 2023.

Conclusion

The adjoining properties have significantly greater setbacks from adjoining housing than paired sales data shows is needed to maintain property values.

The paired sales analysis shows no impact on home values due to abutting or adjoining a solar farm as well as no impact to abutting or adjacent vacant residential or agricultural land where the solar farm is properly setback and/or screened. The criteria that typically correlates with downward adjustments on property values such as noise, odor, and traffic all indicate that a solar farm is a compatible use for rural and suburban residential transition areas and that it would function in a harmonious manner with this area. In the Southwest where screening is more difficult or accomplished through visual barriers instead of landscaping, greater setbacks have been used in some cases and physical walls or slats in fencing have also been used.

Data from the university studies, broker commentary, and other appraisal studies support a finding of no impact on property value adjoining a solar farm with proper setbacks and/or screening.

Very similar solar farms in very similar areas have been found by hundreds of towns and counties not to have a substantial negative effect to abutting or adjoining properties, and many of those findings of no impact have been upheld by appellate courts. Similar solar farms have been approved with adjoining agricultural uses, schools, churches, and residential developments.

Based on the data and analysis in this report, it is my professional opinion that the solar farm proposed at the subject property will not be injurious to or diminish the use, value and enjoyment of other property in the immediate vicinity for the purposes already permitted. It is further my opinion that the use will not impede the normal and orderly development and improvement of surrounding property for uses permitted by right in the zoning district of the surrounding property.

The data that I have researched includes new home construction as well as new subdivision development adjoining solar farms which speaks to a finding of no impact on future development potential on adjoining uses.

I note that some of the positive implications of a solar farm that have been expressed by people living next to solar farms include protection from future development of residential developments or other more intrusive uses, reduced dust, odor and chemicals from farming operations, protection from light pollution at night, it's quiet, and there is minimal traffic.

If you have any questions, please let me know.

Sincerely,

RICHARD C. KIRKLAND, JR. STATE CERTIFIED NORTH CAROLINA REAL ESTATE APPRAISER A4359 GENERAL APPRAISER

RICHARD C. KIRKLAND, JR. MAI DESIGNATED SEPT. 28, 2001

Richard C. Kirkland, Jr., MAI
NC Certified General Appraiser #A4359
NM Temporary Practiced Permit #REA22010-TP

Table of Contents

I. Proposed Project and Adjoining Uses

Proposed Use Description

This proposed 96 MW with a 48 MWAC Battery Energy Storage System (BESS) solar farm is proposed to be constructed on approximately 758.96 acres of a parent tract with 8,225 acres off NM 14 Highway, near Santa Fe, Santa Fe County, New Mexico.

Adjoining Properties

I have considered adjoining uses and included a map to identify each parcel's location. The closest adjoining home will be 2,170 feet from the closest panel. The average distance is 3,762 feet.

The breakdown of those uses by acreage and number of parcels is summarized below.

Adjoining Use Breakdown

	Acreage	Parcels
Residential	1.17%	76.92%
Agricultural	98.83%	23.08%
Total	**100.00%**	**100.00%**

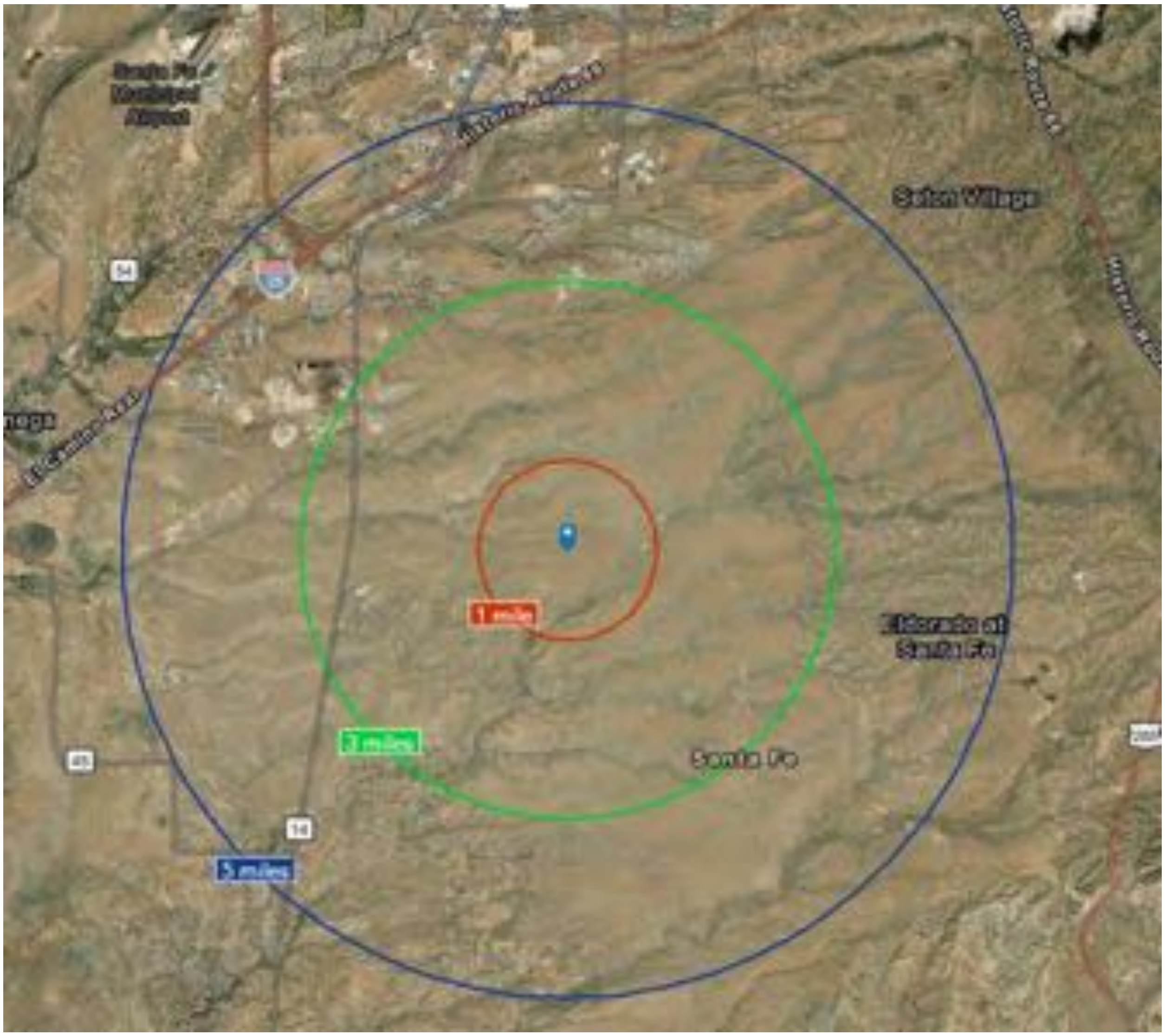
Overall Map

Surrounding Uses

#	MAP ID	Owner	GIS Data Acres	Present Use	Adjoin Acres	Adjoin Parcels	Distance (ft) Home/Panel
1	99309984	Rancho	664.13	Agricultural	5.35%	7.69%	N/A
2	992220715	Staple	8225.00	Agricultural	66.20%	7.69%	N/A
3	910009647	New Mexico	3390.00	Agricultural	27.28%	7.69%	N/A
4	950001647	Elkelenboom	18.77	Residential	0.15%	7.69%	2,170
5	950001650	Marshal	19.63	Residential	0.16%	7.69%	N/A
6	950001651	Norman	17.28	Residential	0.14%	7.69%	2,520
7	950001653	Phyfe	12.84	Residential	0.10%	7.69%	2,780
8	950001655	Ihlefeld	12.19	Residential	0.10%	7.69%	3,335
9	950001657	Brom	13.00	Residential	0.10%	7.69%	3,905
10	950001659	Willford	12.75	Residential	0.10%	7.69%	4,155
11	950001661	Cisneros	12.51	Residential	0.10%	7.69%	4,590
12	950001663	Teague	12.78	Residential	0.10%	7.69%	4,965
13	950001665	Ruben	14.21	Residential	0.11%	7.69%	5,440
		Total	**12425.090**		**100.00%**	**100.00%**	3,762

Demographics Around Subject Property

I have pulled demographic data around a 1-mile, 3-mile and 5-mile radius from the middle of the project as shown on the following pages.



Housing Profile

87508, Santa Fe, New Mexico
Ring: 1 mile radius

Prepared by Esri
Latitude: 35.54233
Longitude: -106.01131

Population		Households	
2010 Total Population	31	2022 Median Household Income	$85,825
2020 Total Population	32	2027 Median Household Income	$100,000
2022 Total Population	32	2022-2027 Annual Rate	3.10%
2027 Total Population	31		
2022-2027 Annual Rate	-0.63%		

	Census 2010		2022		2027	
Housing Units by Occupancy Status and Tenure	Number	Percent	Number	Percent	Number	Percent
Total Housing Units	16	100.0%	16	100.0%	16	100.0%
Occupied	16	100.0%	16	100.0%	16	100.0%
Owner	13	81.2%	13	81.2%	13	81.2%
Renter	3	18.8%	3	18.8%	3	18.8%
Vacant	1	6.2%	0	0.0%	0	0.0%

	2022		2027	
Owner Occupied Housing Units by Value	Number	Percent	Number	Percent
Total	12	100.0%	12	100.0%
<$50,000	1	8.3%	0	0.0%
$50,000-$99,999	0	0.0%	0	0.0%
$100,000-$149,999	0	0.0%	0	0.0%
$150,000-$199,999	0	0.0%	0	0.0%
$200,000-$249,999	1	8.3%	1	8.3%
$250,000-$299,999	1	8.3%	0	0.0%
$300,000-$399,999	1	8.3%	1	8.3%
$400,000-$499,999	3	25.0%	4	33.3%
$500,000-$749,999	4	33.3%	5	41.7%
$750,000-$999,999	1	8.3%	1	8.3%
$1,000,000-$1,499,999	0	0.0%	0	0.0%
$1,500,000-$1,999,999	0	0.0%	0	0.0%
$2,000,000+	0	0.0%	0	0.0%
Median Value	$466,667		$500,000	
Average Value	$466,667		$531,250	

Census 2010 Housing Units	Number	Percent
Total	16	100.0%
In Urbanized Areas	0	0.0%
In Urban Clusters	0	0.0%
Rural Housing Units	16	100.0%

Data Note: Persons of Hispanic Origin may be of any race.
Source: Esri forecasts for 2022 and 2027. U.S. Census Bureau 2010 decennial Census data converted by Esri into 2020 geography.

February 05, 2023

Housing Profile

87508, Santa Fe, New Mexico
Ring: 3 mile radius

Prepared by Esri
Latitude: 35.54233
Longitude: -106.01131

Population		Households	
2010 Total Population	1,305	2022 Median Household Income	$76,581
2020 Total Population	1,263	2027 Median Household Income	$86,853
2022 Total Population	1,253	2022-2027 Annual Rate	2.55%
2027 Total Population	1,215		
2022-2027 Annual Rate	-0.61%		

	Census 2010		2022		2027	
Housing Units by Occupancy Status and Tenure	Number	Percent	Number	Percent	Number	Percent
Total Housing Units	580	100.0%	580	100.0%	580	100.0%
Occupied	522	90.0%	524	90.3%	511	88.1%
Owner	434	74.8%	426	73.4%	418	72.1%
Renter	88	15.2%	98	16.9%	93	16.0%
Vacant	58	10.0%	56	9.7%	70	12.1%

	2022		2027	
Owner Occupied Housing Units by Value	Number	Percent	Number	Percent
Total	426	100.0%	419	100.0%
<$50,000	18	4.2%	9	2.1%
$50,000-$99,999	3	0.7%	1	0.2%
$100,000-$149,999	9	2.1%	10	2.4%
$150,000-$199,999	8	1.9%	4	1.0%
$200,000-$249,999	28	6.6%	18	4.3%
$250,000-$299,999	40	9.4%	28	6.7%
$300,000-$399,999	79	18.5%	71	16.9%
$400,000-$499,999	108	25.4%	127	30.3%
$500,000-$749,999	103	24.2%	116	27.7%
$750,000-$999,999	19	4.5%	25	6.0%
$1,000,000-$1,499,999	9	2.1%	9	2.1%
$1,500,000-$1,999,999	1	0.2%	0	0.0%
$2,000,000+	1	0.2%	1	0.2%
Median Value	$425,926		$453,937	
Average Value	$453,052		$486,575	

Census 2010 Housing Units	Number	Percent
Total	580	100.0%
In Urbanized Areas	23	4.0%
In Urban Clusters	132	22.8%
Rural Housing Units	425	73.3%

Data Note: Persons of Hispanic Origin may be of any race.
Source: Esri forecasts for 2022 and 2027. U.S. Census Bureau 2010 decennial Census data converted by Esri into 2020 geography.

February 05, 2023

Housing Profile

87508, Santa Fe, New Mexico
Ring: 5 mile radius

Prepared by Esri
Latitude: 35.54233
Longitude: -106.01131

Population		Households	
2010 Total Population	11,926	2022 Median Household Income	$80,999
2020 Total Population	12,792	2027 Median Household Income	$90,986
2022 Total Population	12,815	2022-2027 Annual Rate	2.35%
2027 Total Population	13,673		
2022-2027 Annual Rate	1.30%		

	Census 2010		2022		2027	
Housing Units by Occupancy Status and Tenure	Number	Percent	Number	Percent	Number	Percent
Total Housing Units	4,729	100.0%	5,341	100.0%	5,709	100.0%
Occupied	4,361	92.2%	5,002	93.7%	5,378	94.2%
Owner	3,601	76.1%	4,179	78.2%	4,558	79.8%
Renter	760	16.1%	823	15.4%	820	14.4%
Vacant	368	7.8%	340	6.4%	330	5.8%

	2022		2027	
Owner Occupied Housing Units by Value	Number	Percent	Number	Percent
Total	4,179	100.0%	4,558	100.0%
<$50,000	147	3.5%	72	1.6%
$50,000-$99,999	61	1.5%	29	0.6%
$100,000-$149,999	111	2.7%	74	1.6%
$150,000-$199,999	87	2.1%	59	1.3%
$200,000-$249,999	309	7.4%	251	5.5%
$250,000-$299,999	444	10.6%	369	8.1%
$300,000-$399,999	891	21.3%	906	19.9%
$400,000-$499,999	1,084	25.9%	1,396	30.6%
$500,000-$749,999	742	17.8%	967	21.2%
$750,000-$999,999	201	4.8%	314	6.9%
$1,000,000-$1,499,999	44	1.1%	45	1.0%
$1,500,000-$1,999,999	7	0.2%	6	0.1%
$2,000,000+	51	1.2%	70	1.5%
Median Value	$403,644		$437,178	
Average Value	$442,749		$489,288	

Census 2010 Housing Units	Number	Percent
Total	4,729	100.0%
In Urbanized Areas	1,756	37.1%
In Urban Clusters	1,129	23.9%
Rural Housing Units	1,844	39.0%

Data Note: Persons of Hispanic Origin may be of any race.
Source: Esri forecasts for 2022 and 2027. U.S. Census Bureau 2010 decennial Census data converted by Esri into 2020 geography.

February 05, 2023

II. Methodology and Discussion of Issues

Standards and Methodology

I conducted this analysis using the standards and practices established by the Appraisal Institute and that conform to the Uniform Standards of Professional Appraisal Practice. The analyses and methodologies contained in this report are accepted by all major lending institutions, and they are used in New Mexico and across the country as the industry standard by certified appraisers conducting appraisals, market analyses, or impact studies and are considered adequate to form an opinion of the impact of a land use on neighboring properties. These standards and practices have also been accepted by the courts at the trial and appellate levels and by federal courts throughout the country as adequate to reach conclusions about the likely impact a use will have on adjoining or abutting properties.

The aforementioned standards compare property uses in the same market and generally within the same calendar year so that fluctuating markets do not alter study results. Although these standards do not require a linear study that examines adjoining property values before and after a new use (e.g. a solar farm) is developed, some of these studies do in fact employ this type of analysis. Comparative studies, as used in this report, are considered an industry standard.

The type of analysis employed is a Matched Pair Analysis or Paired Sales Analysis. This methodology is outlined in **The Appraisal of Real Estate**, Twelfth Edition by the Appraisal Institute pages 438-439. It is further detailed in **Real Estate Damages**, Third Edition, pages 33-36 by Randall Bell PhD, MAI. Paired sales analysis is used to support adjustments in appraisal work for factors ranging from the impact of having a garage, golf course view, or additional bedrooms. It is an appropriate methodology for addressing the question of impact of an adjoining solar farm. The paired sales analysis is based on the theory that when two properties are in all other respects equivalent, a single difference can be measured to indicate the difference in price between them. Dr. Bell describes it as comparing a test area to control areas. In the example provided by Dr. Bell he shows five paired sales in the test area compared to 1 to 3 sales in the control areas to determine a difference. I have used 3 sales in the control areas in my analysis for each sale developed into a matched pair.

Determining what is an External Obsolescence

An external obsolescence is a use of property that, because of its characteristics, might have a negative impact on the value of adjacent or nearby properties because of identifiable impacts. Determining whether a use would be considered an external obsolescence requires a study that isolates that use, eliminates any other causing factors, and then studies the sales of nearby versus distant comparable properties. The presence of one or a combination of key factors does not mean the use will be an external obsolescence, but a combination of these factors tends to be present when market data reflects that a use is an external obsolescence.

External obsolescence is evaluated by appraisers based on several factors. These factors include but are not limited to:

1) Traffic. Solar Farms are not traffic generators.

2) Odor. Solar farms do not produce odor.

3) Noise. Solar farms generate no noise concerns and are silent at night.

4) Environmental. Solar farms do not produce toxic or hazardous waste. Grass is maintained underneath the panels so there is minimal impervious surface area.

5) Appearance/Viewshed. This is the one area that potentially applies to solar farms. However, solar farms are generally required to provide significant setbacks and landscaping buffers to address that concern. Furthermore, any consideration of appearance of viewshed impacts has to be considered in comparison with currently allowed uses on that site. For example if a residential subdivision is already an allowed use, the question becomes in what way does the appearance impact adjoining property owners above and beyond the appearance of that allowed subdivision or other similar allowed uses.

6) Other factors. I have observed and studied many solar farms and have never observed any characteristic about such facilities that prevents or impedes neighbors from fully using their homes or farms or businesses for the use intended.

Relative Solar Farm Sizes

Solar farms have been increasing in size in recent years. Much of the data collected is from existing, older solar farms of smaller size, but there are numerous examples of sales adjoining 75 to 80 MW facilities that show a similar trend as the smaller solar farms. This is understandable given that the primary concern relative to a solar farm is the appearance or view of the solar farm, which is typically addressed through setbacks and landscaping buffers. The relevance of data from smaller solar farms to larger solar farms is due to the primary question being one of appearance. If the solar farm is properly screened, then little of the solar farm would be seen from adjoining property regardless of how many acres are involved.

Larger solar farms are often set up in sections where any adjoining owner would only be able to see a small section of the project even if there were no landscaping screen. Once a landscaping screen is in place, the primary view is effectively the same whether adjoining a 5 MW, 20 MW or 100 MW facility.

I have split out the data for the matched pairs adjoining larger solar farms only to illustrate the similarities later in this report.

Steps Involved in the Analysis

The paired sales analysis employed in this report follows the following process:

1. Identify sales of property adjoining existing solar farms.
2. Compare those sales to similar property that does not adjoin an existing solar farm.
3. Confirmation of sales are noted in the analysis write ups.
4. Distances from the homes to panels are included as a measure of the setbacks.
5. Topographic differences across the solar farms themselves are likewise noted along with demographic data for comparing similar areas.

There are a number of Sale/Resale comparables included in the write ups, but most of the data shown is for sales of homes after a solar farm has been announced (where noted) or after a solar farm has been constructed.

III. Research on Solar Farms

A. Appraisal Market Studies

I have also considered a number of impact studies completed by other appraisers as detailed below.

CohnReznick – Property Value Impact Study: Adjacent Property Values Solar Impact Study: A Study of Eight Existing Solar Facilities

Patricia McGarr, MAI, CRE, FRICS, CRA and Andrew R. Lines, MAI with CohnReznick completed an impact study for a proposed solar farm in Cheboygan County, Michigan completed on June 10, 2020. I am familiar with this study as well as a number of similar such studies completed by CohnReznick. I have not included all of these studies but I submit this one as representative of those studies.

This study addresses impacts on value from eight different solar farms in Michigan, Minnesota, New Mexico, Illinois, Virginia and North Carolina. These solar farms are 19.6 MW, 100 MW, 11.9 MW, 23 MW, 71 MW, 61 MW, 40 MW, and 19 MW for a range from 11.9 MW to 100 MW with an average of 31 MW and a median of 31.5 MW. They analyzed a total of 24 adjoining property sales in the Test Area and 81 comparable sales in the Control Area over a five-year period.

The conclusion of this study is that there is no evidence of any negative impact on adjoining property values based on sales prices, conditions of sales, overall marketability, potential for new development or rate of appreciation.

Christian P. Kaila & Associates – Property Impact Analysis – Proposed Solar Power Plant Guthrie Road, Stuarts Draft, Augusta County, Virginia

Christian P. Kaila, MAI, SRA and George J. Finley, MAI developed an impact study as referenced above dated June 16, 2020. This was for a proposed 83 MW facility on 886 acres.

Mr. Kaila interviewed appraisers who had conducted studies and reviewed university studies and discussed the comparable impacts of other development that was allowed in the area for a comparative analysis of other impacts that could impact viewshed based on existing allowed uses for the site. He also discussed in detail the various other impacts that could cause a negative impact and how solar farms do not have such characteristics.

Mr. Kaila also interviewed county planners and real estate assessors in eight different Virginia counties with none of the assessor's identifying any negative impacts observed for existing solar projects.

Mr. Kaila concludes on a finding of no impact on property values adjoining the indicated solar farm.

Fred Beck, MAI, CCIM – Impact Analysis in Lincoln County 2013

Mr. Fred Beck, MAI, CCIM completed an impact analysis in 2013 for a proposed solar farm that concluded on a negative impact on value. That report relied on a single cancelled contract for an adjoining parcel where the contracted buyers indicated that the solar farm was the reason for the cancellation. It also relied on the activities of an assessment impact that was applied in a nearby county.

Mr. Beck was interviewed as part of the Christian Kalia study noted above. From that I quote "Mr. Beck concluded on no effect on moderate priced homes, and only a 5% change in his limited research of higher priced homes. His one sale that fell through is hardly a reliable sample. It also was misleading on Mr. Beck's part to report the lower re-assessments since the primary cause of the re-assesments were based on the County Official, who lived adjacent to the solar farm, appeal to the assessor for reductions with his own home." In that Clay County Case study the noted lack of lot sales after announcement of the solar farm also coincided with the recession in 2008/2009 and lack of lot sales effectively defined that area during that time.

I further note, that I was present at the hearing where Mr. Beck presented these findings and the predominance of his argument before the Lincoln County Board of Commissioner's was based on the one cancelled sale as well as a matched pair analysis of high-end homes adjoining a four-story call center. He hypothesized that a similar impact from that example could be compared to being adjacent solar farm without explaining the significant difference in view, setbacks, landscaping, traffic, light, and noise. Furthermore, Mr. Beck did have matched pairs adjoining a solar farm in his study that he put in the back of his report and then ignored as they showed no impact on property value.

Also noted in the Christian Kalia interview notes is a response from Mr. Beck indicating that in his opinion "the homes were higher priced homes and had full view of the solar farm." Based on a description of screening so that "the solar farm would not be in full view to adjoining property owners. Mr. Beck said in that case, he would not see any drop in property value."

NorthStar Appraisal Company – Impact Analysis for Nichomus Run Solar, Pilesgrove, NJ, September 16, 2020

Mr. William J. Sapio, MAI with NorthStar Appraisal Company considered a matched pair analysis for the potential impact on adjoining property values to this proposed 150 MW solar farm. Mr. Sapio considered sales activity in a subdivision known as Point of Woods in South Brunswick Township and identified two recent new homes that were constructed and sold adjoining a 13 MW solar farm and compared them to similar homes in that subdivision that did not adjoin the solar farm. These homes sold in the $1,290,450 to $1,336,613 price range and these homes were roughly 200 feet from the closest solar panel.

Based on this analysis, he concluded that the adjoining solar farm had no impact on adjoining property value.

MR Valuation Consulting, LLC – The Kuhl Farm Solar Development and The Fischer Farm Solar Development – June 7, 2012

Mr. Mark Pomykacaz, MAI MRICS with MR Valuation Consulting, LLC considered a matched pair analysis for sales near these solar farms. The sales data presented supported a finding of no impact on property value for nearby and adjoining homes and concludes that there is no impact on marketing time and no additional risk involved with owning, building, or selling properties next to the solar farms.

Mary McClinton Clay, MAI – McCracken County Solar Project Value Impact Report, July 10, 2021

Ms. Mary Clay, MAI reviewed a report by Kirkland Appraisals in this case and also provided a differing opinion of impact. She cites a number of other appraisal studies and interestingly finds fault with heavily researched opinions, while praising the results of poorly researched studies that found the opposing view.

Her analysis includes details from solar farms that show no impact on value, but she dismisses those.

She cites the University of Texas study noted later in this report, but she cites only isolated portions of that study to conclude the opposite of what that study specifically concludes.

She cites the University of Rhode Island study noted alter in this report, but specifically excludes the conclusion of that study that in rural areas they found no impact on property value.

She cites lot sales near Spotsylvania Solar without confirming the purchase prices with brokers as indicative of market impact and has made no attempt to compare lot prices that are contemporaneous. In her 5 lot sales that she identifies, all of the lot prices decline with time from 2015 through 2019. This includes the 3 lot sales prior to the approval of the solar farm. The decrease in lot values shown in this chart are more indicative of the trend in the market, than of any impact related to the solar farm. Otherwise, how does she explain the drop in price from 2015 to 2017 prior to the solar farm approval.

She considers data at McBride Place Solar Farm and does a sale/resale analysis based on Zillow Home Value Index, which is not a reliable indication for appreciation in the market. She then adjusted her initial sales prior to the solar farm over 7 years to determine what she believes the home should have appreciated by and then compares that to an actual sale. She has run no tests or any analysis to show that the appreciation rates she is using are consistent with the market but more importantly she has not attempted to confirm any of these sales with market participants. I have spoken with brokers active in the sales that she cites and they have all indicated that the solar farm was not a negative factor in marketing or selling those homes.

She has considered lot sales at Sunshine Farms in Grandy, NC. She indicates that the lots next to the solar farm are selling for less than lots not near the solar farm, but she is actually using lot sales next to the solar farm prior to the solar farm being approved. She also ignores recent home sales adjoining this solar farm after it was built that show no impact on property value.

She also notes a couple of situations where solar developers have purchased adjoining homes and resold them or where a neighbor agreement was paid as proof of a negative impact on property value. Given that there are over 2,500 solar farms in the USA as of 2018 according to the U.S. Energy Information Administration and there are only a handful of such examples, this is clearly not an industry standard but a business decision. Furthermore, solar developers are not in the business of flipping homes and are in a position very similar to a bank that acquires a home as OREO (Other Real Estate Owned), where homes are frequently sold at discounted prices, not because of any drop in value, but because they are not a typically motivated seller. Market value requires an analysis of a typically motivated buyer and seller. So these are not good indicators of market value impacts.

The comments throughout this study are heavy in adjectives, avoids stating facts contrary to the conclusion and shows a strong selection bias.

Conclusion of Impact Studies

Of the five studies noted two included actual sales data to derive an opinion of no impact on value. The two studies to conclude on a negative impact includes the Fred Beck study based on no actual sales data, and he has since indicated that with landscaping screens he would not conclude on a negative impact. The other study by Mary Clay shows improper adjustments for time, a lack of confirmation of sales comparables, and exclusion of data that does not support her position.

I have relied on these studies as additional support for the findings in this impact analysis.

B. Articles

I have also considered a number of articles on this subject as well as conclusions and analysis as noted below.

Farm Journal Guest Editor, March 22, 2021 – Solar's Impact on Rural Property Values

Andy Ames, ASFMRA (American Society of Farm Managers and Rural Appraisers) published this article that includes a discussion of his survey of appraisers and studies on the question of property value related to solar farms. He discusses the university studies that I have cited as well as Patricia McGarr, MAI.

He also discusses the findings of Donald A. Fisher, ARA, who served six years at the Chair of the ASFMRA's National Appraisal Review Committee. He is also the Executive Vice President of the CNY Pomeroy Appraiser and has conducted several market studies on solar farms and property impact. He is quoted in the article as saying, "Most of the locations were in either suburban or rural areas, and all of those studies found either a neutral impact, or ironically, a positive impact, where values on properties after installation of solar farms went up higher than time trends."

Howard Halderman, AFM, President and CEO of Halderman Real Estate and Farm Management attended the ASFMRA solar talk hosted by the Indiana Chapter of the ASFMRA and he concludes that other rural properties would likely see no impact and farmers and landowners shown even consider possible benefits. "In some cases, farmers who rent land to a solar company will insure the viability of their farming operation for a longer time period. This makes them better long-term tenants or land buyers so one can argue that higher rents and land values will follow due to the positive impact the solar leases offer."

More recently in August 2022, Donald Fisher, ARA, MAI and myself led a webinar on this topic for the ASFMRA discussing the issues, the university studies and specific examples of solar farms having no impact on adjoining property values.

National Renewable Energy Laboratory – Top Five Large-Scale Solar Myths, February 3, 2016

Megan Day reports form NREL regarding a number of concerns neighbors often express. Myth #4 regarding property value impacts addresses specifically the numerous studies on wind farms that show no impact on property value and that solar farms have a significantly reduced visual impact from wind farms. She highlights that the appearance can be addressed through mitigation measures to reduce visual impacts of solar farms through vegetative screening. Such mitigations are not available to wind farms given the height of the windmills and again, those studies show no impact on value adjoining wind farms.

North Carolina State University: NC Clean Energy Technology Center White Paper: Balancing Agricultural Productivity with Ground-Based Solar Photovoltaic (PV) Development (Version 2), May 2019

Tommy Cleveland and David Sarkisian wrote a white paper for NCSU NC Clean Energy Technology Center regarding the potential impacts to agricultural productivity from a solar farm use. I have interviewed Tommy Cleveland on numerous occasions and I have also heard him speak on these issues at length as well. He addresses many of the common questions regarding how solar farms work and a detailed explanation of how solar farms do not cause significant impacts on the soils, erosion and other such concerns. This is a heavily researched paper with the references included.

North Carolina State University: NC Clean Energy Technology Center White Paper: Health and Safety Impacts of Solar Photovoltaics, May 2017

Tommy Cleveland wrote a white paper for NCSU NC Clean Energy Technology Center regarding the health and safety impacts to address common questions and concerns related to solar farms. This is a heavily researched white paper addressing questions ranging from EMFs, fire safety, as well as vegetation control and the breakdown of how a solar farm works.

C. Broker Commentary

In the process of working up the matched pairs used later in this report, I have collected comments from brokers who have actually sold homes adjoining solar farms indicating that the solar farm had no impact on the marketing, timing, or sales price for the adjoining homes. Comments are noted in specific examples later in this report.

IV. University Studies

I have also considered the following studies completed by four different universities related to solar farms and impacts on property values.

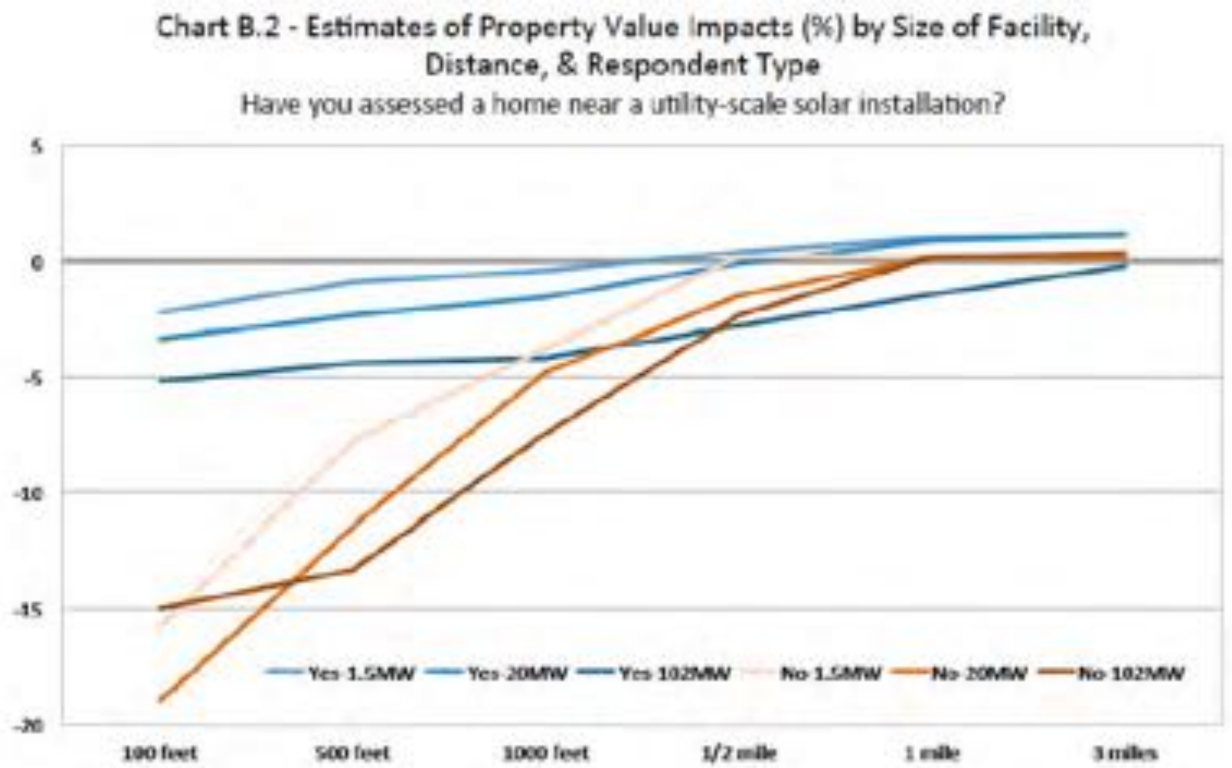
A. University of Texas at Austin, May 2018

An Exploration of Property-Value Impacts Near Utility-Scale Solar Installations

This study considers solar farms from two angles. First it looks at where solar farms are being located and concludes that they are being located primarily in low density residential areas where there are fewer homes than in urban or suburban areas.

The second part is more applicable in that they conducted a survey of appraisers/assessors on their opinions of the possible impacts of proximity to a solar farm. They consider the question in terms of size of the adjoining solar farm and how close the adjoining home is to the solar farm. I am very familiar with this part of the study as I was interviewed by the researchers multiple times as they were developing this. One very important question that they ask within the survey is very illustrative. They asked if the appraiser being surveyed had ever appraised a property next to a solar farm. There is a very noticeable divide in the answers provided by appraisers who have experience appraising property next to a solar farm versus appraisers who self-identify as having no experience or knowledge related to that use.

On Page 16 of that study they have a chart showing the responses from appraisers related to proximity to a facility and size of the facility, but they separate the answers as shown below with appraisers with experience in appraising properties next to a solar farm shown in blue and those inexperienced shown in brown. Even within 100 feet of a 102 MW facility the response from experienced appraisers were -5% at most on impact. While inexperienced appraisers came up with significantly higher impacts. This chart clearly shows that an uninformed response widely diverges from the sales data available on this subject.



Furthermore, the question cited above does not consider any mitigating factors such as landscaping buffers or screens which would presumably reduce the minor impacts noted by experienced appraisers on this subject.

The conclusion of the researchers is shown on Page 23 indicated that "Results from our survey of residential home assessors show that the majority of respondents believe that proximity to a solar installation has either no impact or a positive impact on home values."

This analysis supports the conclusion of this report that the data supports no impact on adjoining property values.

B. University of Rhode Island, September 2020

Property Value Impacts of Commercial-Scale Solar Energy in Massachusetts and Rhode Island

The University of Rhode Island published a study entitled **Property Value Impacts of Commercial-Scale Solar Energy in Massachusetts and Rhode Island** on September 29, 2020 with lead researchers being Vasundhara Gaur and Corey Lang. I have read that study and interviewed Mr. Corey Lang related to that study. This study is often cited by opponents of solar farms but the findings of that study have some very specific caveats according to the report itself as well as Mr. Lang from the interview.

While that study does state in the Abstract that they found depreciation of homes within 1-mile of a solar farm, that impact is limited to non-rural locations. On Pages 16-18 of that study under Section 5.3 Heterogeneity in treatment effect they indicate that the impact that they found was limited to non-rural locations with the impact in rural locations effectively being zero. For the study they defined "rural" as a municipality/township with less than 850 population per square mile.

They further tested the robustness of that finding and even in areas up to 2,000 population per square mile they found no statistically significant data to suggest a negative impact.

Where they did find negative impacts was in high population density areas that was largely a factor of running the study in Massachusetts and Rhode Island which the study specifically cites as being the 2nd and 3rd most population dense states in the USA. Mr. Lang in conversation as well as in recorded presentations has indicated that the impact in these heavily populated areas may reflect a loss in value due to the scarce greenery in those areas and not specifically related to the solar farm itself. In other words, any development of that site might have a similar impact on property value.

Based on this study I have checked the population for both Santa Fe South CCD of Santa Fe County. Santa Fe South CCD has a population of 42,693 for 2022 based on HomeTownLocator which uses the US Census data and a total area of 1,377 square miles. This indicates a population density of 31 people per square mile which puts this well below the threshold indicated by the Rhode Island Study.

I therefore conclude that the Rhode Island Study supports the indication of no impact on adjoining properties for the proposed solar farm project.

Santa Fe South Division Data & Demographics (As of July 1, 2022)

POPULATION	
Total Population	42,693 (100%)
Population in Households	41,588 (97.4%)
Population in Families	32,762 (76.7%)
Population in Group Quarters[1]	1,105 (2.6%)
Population Density	31
Diversity Index[2]	73

HOUSING	
Total HU (Housing Units)	20,355 (100%)
Owner Occupied HU	15,938 (78.3%)
Renter Occupied HU	2,211 (10.9%)
Vacant Housing Units	2,206 (10.8%)
Median Home Value	$407,366
Average Home Value	$488,148
Housing Affordability Index[3]	97

INCOME	
Median Household Income	$82,213
Average Household Income	$117,928
% of Income for Mortgage[4]	26%
Per Capita Income	$50,176
Wealth Index[5]	148

HOUSEHOLDS	
Total Households	18,149
Average Household Size	2.29
Family Households	11,631
Average Family Size	3

C. *Georgia Institute of Technology, October 2020*

Utility-Scale Solar Farms and Agricultural Land Values

This study was completed by Nino Abashidze as Post-Doctoral Research Associate of Health Economics and Analytics Labe (HEAL), School of Economics, Georgia Institute of Technology. This research was started at North Carolina State University and analyzes properties near 451 utility-scale ground-mount solar installations in NC that generate at least 1 MW of electric power. A total of 1,676 land sales within 5-miles of solar farms were considered in the analysis.

This analysis concludes on Page 21 of the study "Although there are no direct effects of solar farms on nearby agricultural land values, we do find evidence that suggests construction of a solar farm may create a small, positive, option -value for land owners that is capitalized into land prices. Specifically, after construction of a nearby solar farm, we find that agricultural land that is also located near transmission infrastructure may increase modestly in value."

This study supports a finding of no impact on adjoining agricultural property values and in some cases could support a modest increase in value.

D. *Master's Thesis: ECU by Zachary Dickerson July 2018*

A Solar Farm in *My* Backyard? Resident Perspectives of Utility-Scale Solar in Eastern North Carolina

This study was completed as part of a Master of Science in Geography Master's Thesis by Zachary Dickerson in July 2018. This study sets out to address three questions:

1. Are there different aspects that affect resident satisfaction regarding solar farms?

2. Are there variations in satisfaction for residents among different geographic settings, e.g. neighborhoods adjacent to the solar farms or distances from the solar farms?

3. How can insight from both the utility and planning sectors, combined with knowledge gained from residents, fill gaps in communication and policy writing in regard to solar farms?

This was done through survey and interview with adjacent and nearby neighbors of existing solar farms. The positive to neutral comments regarding the solar farms were significantly higher than negative. The researcher specifically indicates on Page 46 "The results show that respondents generally do not believe the solar farms pose a threat to their property values."

The most negative comments regarding the solar farms were about the lack of information about the approval process and the solar farm project prior to construction.

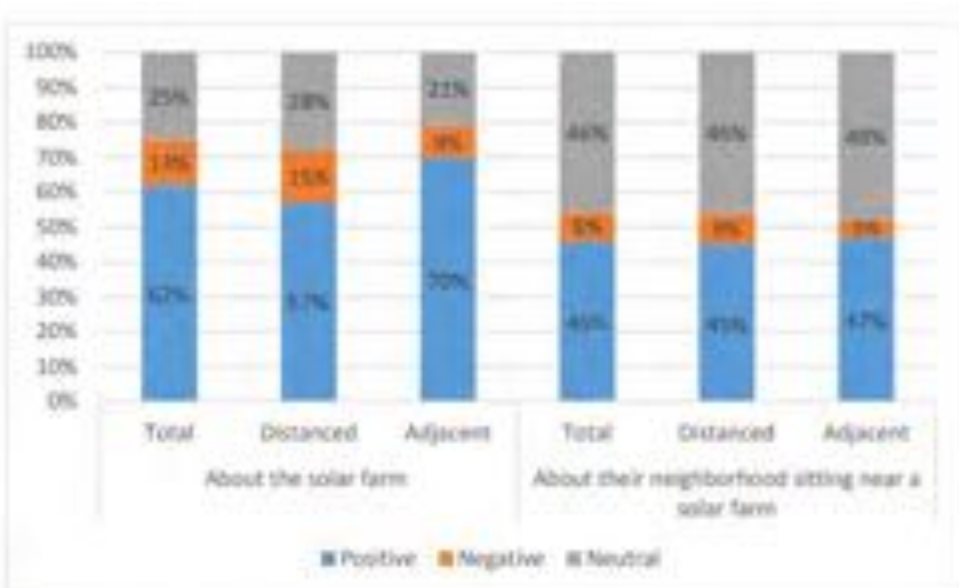


Figure 11: Residents' positive/negative word choices by geographic setting for both questions

V. Assessor Surveys

I have attempted to contact all of the assessor departments in New Mexico to determine how local assessors are handling solar farms and adjoining property values. Not included in the chart below are responses from Guadalupe, Sandoval, and San Juan as they all indicated that they have no solar farms.

The other counties did not respond after three attempts to contact each one. This may indicate that they have no solar farms.

As can be seen in the chart below, of the 5 responses all of the responses have indicated that they make no adjustment to properties adjoining solar farms.

New Mexico Tax Assessors

County	Number of Farms in Operation	Change in adjacent property value
Colfax	3, 1 in planning	No
Curry	1, quite a few in talks	No
Dona Ana	2 owned by city and county	No
Lincoln	1	No
Union	1	No
	Total Responses With Solar	5
	Total Responses "No"	5
	Total Responses "Yes"	0

I have completed surveys in North Carolina, Virginia, Colorado, and Mississippi as well. I have so far found no responses from any assessor that they make negative adjustments to adjoining properties. I currently have 39 responses in North Carolina, 16 responses from Virginia, 4 from Mississippi, and 15 from Colorado. Adding in the 5 responses in New Mexico, I have a total of 79 assessor responses and all 79 indicate either no negative impacts on adjoining property values, or else they did not respond to that part of the question. A total of 69 of the responses were definitively "No" with an additional 10 being "No response" to that question.

I have included the breakdown of that data on the following pages.

NC Assessor Survey on Solar Farm Property Value Impacts

County	Assessor's Name	Number of Farms	Change in Adjacent Property Value
Alexander	Doug Fox	3	No
Buncombe	Lisa Kirbo	1	No
Burke	Daniel Isenhour	3, 2 on 1 parcel, 1 on 3 parcels	No
Cabarrus	Justin	less than 10, more in the works	No
Caldwell	Monty Woods	3 small	No, but will look at data in 2025
Catawba	Lori Ray	14	No
Chatham	Jenny Williams	13	No
Cherokee	Kathy Killian	9	No
Chowan	Melissa Radke	3, I almost operational	No
Clay	Bonnie L. Lyvers		No
Davidson	Libby	1	No
Duplin	Gary Rose	34, 2 more in planning	No
Franklin	Marion Cascone	11	No
Gaston	Traci Hovis	3	No
Gates	Chris Hill	3	No
Granville	Jenny Griffin	8	No
Halifax	C. Shane Lynch	Multiple	No
Hoke	Mandi Davis	4	No
Hyde	Donnie Shumate	1 to supplement egg processing plant	No
Iredell	Wes Long	2, 3 others approved	No
Lee	Lisa Faulkner	8	No
Lincoln	Susan Sain	2	No
Moore	Michael Howery	10	No
New Hanover	Rhonda Garner	35	No
Orange	Chad Phillip	2 or 7 depending on breakdown	No
Pender	Kayla Bolick Futrell	6	No
Person	Russell Jones	9	No
Pitt	Russell D. Hill	8, 1 in planning	No
Randolph	Mark Frick	19	No
Rockingham	Mark C McClintock	6	No
Rutherford	Kim Aldridge	20	No
Sampson	Jim Johnson	9, 1 in construction	No
Scotland	James Brown	15, 1 in process	No
Stokes	Richard Brim	2	No
Surry	Penny Harrison	4, 2 more in process	No
Union	Robin E. Merry	6	No
Vance	Cathy E. Renn	13	No
Warren	John Preston	7	No
Wayne	Alan Lumpkin	32	No
Wilson	William (Witt) Putney	~16	No, mass appraisal standards applied

Responses: 39
Negative Impact on Adjoining Value = Yes: 0
Negative Impact on Adjoining Value = No: 39

VIRGINIA Commissioner of the Revenue

County	Assessor Name	Number of Farms in Operation	Change in adjacent property value
Appomattox	Sara Henderson	1, plus one in process	No
Augusta	W. Jean Shrewsbury	no operational	No
Buckingham	Stephanie D. Love	1	No
Charlotte	Naisha Pridgen Carter	1, several others in the works	No
Clarke	Donna Peake	1	No
Frederick	Seth T. Thatcher	none, 2 appoved for 2022	No, assuming compatible with rural area
Goochland	Mary Ann Davis		No
Hanover	Ed Burnett	1	No
Louisa	Stacey C. Fletcher	2 operational by end of year	No, only if supported by market data
Mecklenburg	Joseph E. "Ed" Taylor		No
Nottoway	Randy Willis with Pearson Assessors		No
Powhatan	Charles Everest	2 approved, 1 built	Likely increase in value
Rockingham	Dan Cullers	no operational	Likely no
Southampton	Amy B. Carr	1	Not normally
Surry	Jonathan F. Judkins	1	None at this time
Westmoreland	William K. Hoover	4	No

Responses: 16
Negative Impact on Adjoining Value = Yes: 0
Negative Impact on Adjoining Value = No: 16

MS Assessor Survey on Solar Farm Property Value Impacts

County	Assessor's Name	Number of Farms	Change in Adjacent Property Value
Desoto	Jeff Fitch	1, 1 in planning	No response
Monroe	Mitzi Presley	2 in planning	No response
Stone	Charles Williams, Jr.	1 in planning	No
Union	Tameri Dunnam	1	No

CO Assessor Survey on Solar Farm Property Value Impacts

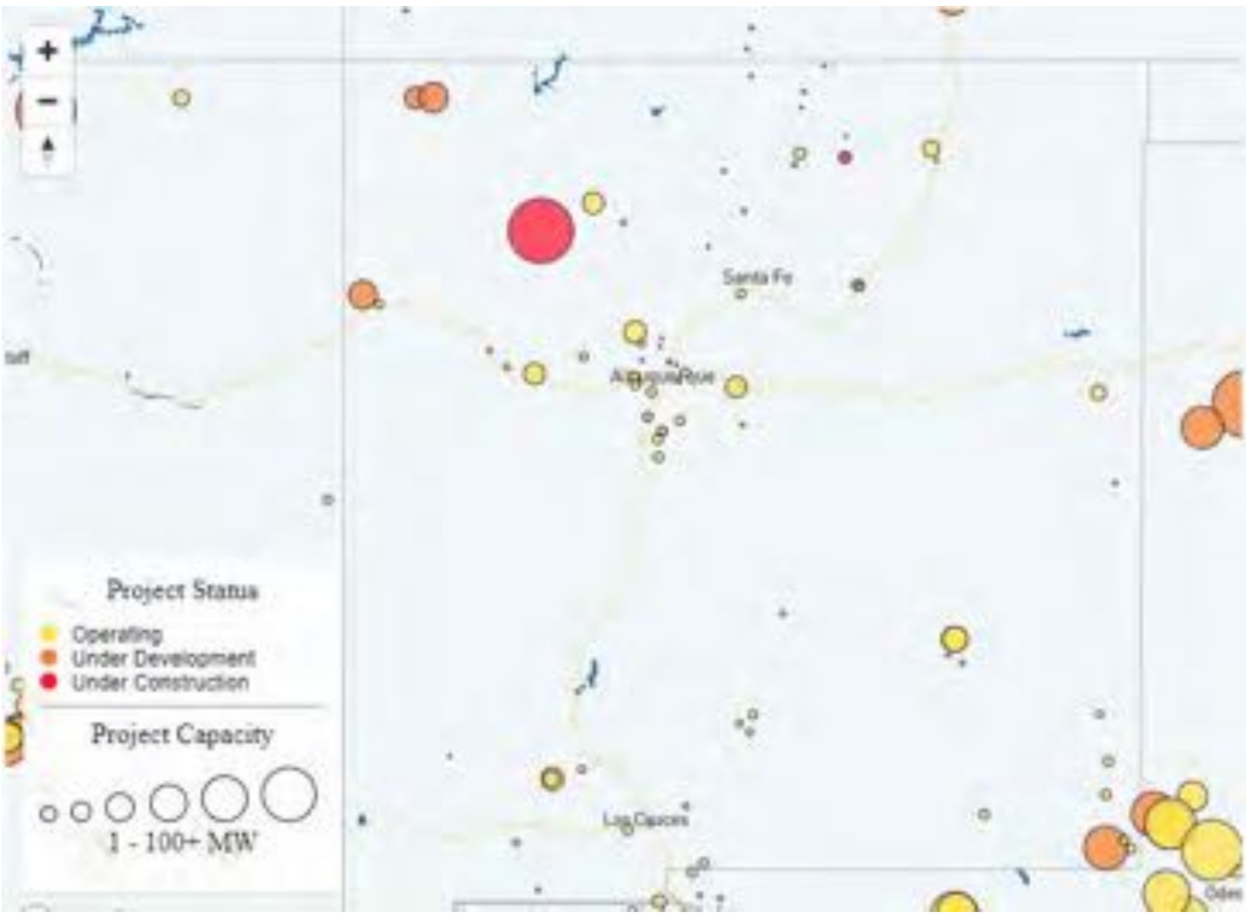
County	Assessor's Name	Number of Farms	Change in Adjacent Property Value
Conejos	Naomi Keys	3 or 4	No response
Denver	Keith Erffmeyer	3	No
Garfield	Jim Yellico (Vicki Riley)	No response	Classification and value could change
Kiowa	Marci Miller	0, 2 in planning	No
La Plata	Carrie Woodson	0, 1 in planning	No response
Las Animas	Jodi Amato	1 operational, 1 in planning	No
Moffat	Charles "Chuck" Cobb	0, 5 in planning	No
Montezuma	Leslie Bugg	3 approved	No
Montrose	Brad Hughes	2, 1 in planning	Maybe, but would be based on sales data
Morgan	Tim Amen	2, operational, 3 in planning	No
Pitkin	Wendy Schultz	1	No
Rio Blanco	Renae Neilson	2	No response
Saguache	Peter Peterson	1	No
San Miguel	Sarah Enders	1	Not enough data
Yuma	Cindy Taylor	1 in planning	No response

Responses: 15
Negative Impact on Adjoining Value = Yes: 0
Negative Impact on Adjoining Value = No: 7
Negative Impact on Adjoining Value = No Response: 8

VI. Summary of Solar Projects In New Mexico

I have researched the solar projects in New Mexico. I identified the solar farms through the Solar Energy Industries Association (SEIA) Major Projects List and then excluded the roof mounted facilities. I focused on larger solar farms over 5 MW.

The map for projects in New Mexico is shown below with only the circles in Yellow representing existing and operating solar farms. The Orange projects are still in the development stage, while the Red represent those in the construction stage. For this analysis on impacts on property value, I have focused on those that are in operation as the only reliable location for identifying the impacts of an existing solar farm.



From this map I have identified 9 solar farms in New Mexico for research. The locations and breakdown of the size and mix of adjoining uses is shown below.

Solar #	Name	State	County	City	Output (MW)	Total Acres	Used Acres	Avg. Dist to home	Closest Home	Adjoining Use by Acre Res	Agri	Agri/Res	Com
923	SunE EPE2	NM	Dona Ana	Las Cruces	12	139.71	139.71	-	-	0%	100%	0%	0%
924	SPS5 Hope	NM	Eddy	Carlsbad	10.1	136.89	136.89	-	-	10%	90%	0%	0%
925	SPS4 Monument	NM	Lea	Hobbs	10.1	440	440	-	-	0%	0%	0%	100%
926	Encino	NM	Sandoval	Rio Rancho	55	455	455	-	-	0%	100%	0%	0%
927	Cimarron	NM	Colfax	Cimarron	30.6	400	400	4,098	3,290	0%	100%	0%	0%
928	Macho Springs	NM	Luna	Nutt	55	-	-	-	-	-	-	-	-
933	Britton	NM	Torance	Moriarty	50	535	535	911	410	8%	91%	0%	1%
934	Roswell	NM	Chaves	Roswell	70	745.64	745.64	531	170	1%	99%	0%	0%
935	Chaves	NM	Chaves	Roswell	70	696.05	696.05	717	205	1%	99%	0%	0%
					9								
				Average	40.3	443.5	443.5	1564	1019	2%	85%	0%	13%
				Median	50.0	447.5	447.5	814	308	1%	99%	0%	0%
				High	70.0	745.6	745.6	4098	3290	10%	100%	0%	100%
				Low	10.1	136.9	136.9	531	170	0%	0%	0%	0%

A quick summary of each solar farm identified is shown on the following pages.

SunE EPE2 Solar, Las Cruces, Dona Ana County, NM

This solar farm is a 12 MW facility that was built in 2011 with no adjoining residential uses.

SPS5 Hope Solar Farm,

This solar farm is 10.1 MW solar farm with nearby residential uses. The closest homes to the east are around 1,800 feet from the nearest panels. The closest homes to the north are around 2,700 feet from the nearest panels. The closest homes to the south are around 3,000 feet from the nearest panel.

I did not identify any recent adjoining home sales for analysis.

This solar farm has no screen and is visible from W. Derrick Road that runs along the southern side of the project. I was unable to find current imagery using GoogleEarth Streetview to determine visibility from the nearby homes as the solar farm was built after the most recent streetview image.

I did run a series of test images along W. Derrick Road using GoogleEarth Streetview to determine relative visibility of the site at different distances. None of these images are anything more than a screen capture of the Streetview at distances of 180 feet, 500 feet, 1,000 feet and 2,000 feet. The panels are detectable within the image at each distance shown, but even at 500 feet they are difficult to discern and blend with the rest of the terrain.

Image facing north from W. Derrick Road from Streetview at 180 feet from the nearest panel

Image facing northeast from W. Derrick Road from Streetview at 500 feet from nearest panel.

Image facing northeast from W. Derrick Road from Streetview at 1,000 feet from nearest panel

Image facing northeast from W. Derrick Road from Streetview at 2,000 feet from nearest panel.

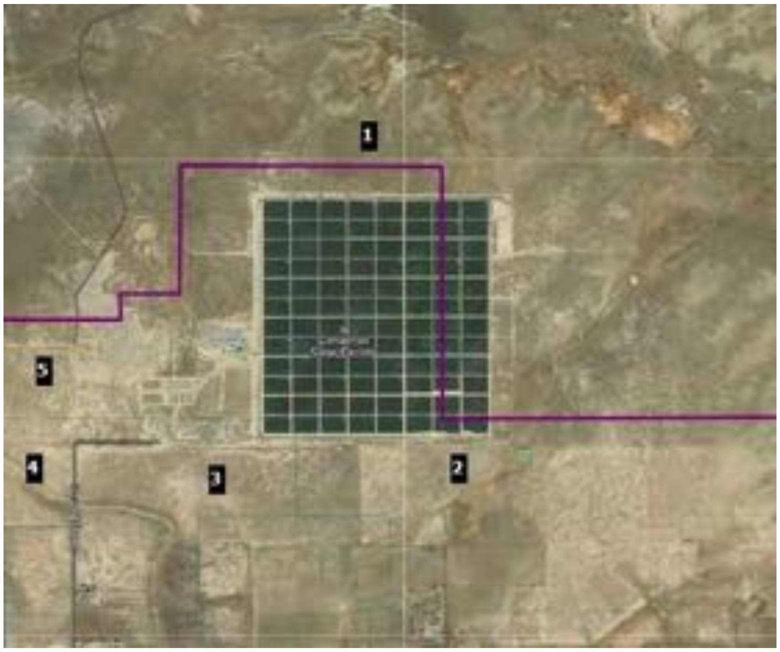
SPS4 Monument Solar, Hobbs, Lea County, NM

This 10.1 MW facility was built in 2012. There are no adjoining residential uses.

Encino Solar, Rio Rancho, Sandoval County, NM

This 55 MW facility was built in 2020. The closest homes to the south are over 4,000 feet away. There is road infrastructure (dirt roads) that lead up to much closer to the site, but there is a vast amount of such dirt road infrastructure in the area with no home construction on most of it.

Cimarron Solar, Cimarron, Colfax County, NM



This 30.6 MW facility was built in 2010. The two adjoining homes are over 3,000 feet away from the nearest solar panel and they are both part of much larger tracts.

Macho Springs Solar, Nutt, Luna County, NM

This 55 MW solar farm was built in 2014 and has no nearby residential uses.

Britton Solar, Moriarty, Torance County, NM

This 50 MW solar farm was built in 2019. Adjoining homes are between 400 and 1,460 feet from the nearest solar panel. The average distance is 911 feet. There is no visual screen for this solar farm.

The double wide home located at 35 Griffin Road sold on December 15, 2020. The asking price was $54,900 for this 3 BR, 2 BA 1,792 square foot home on 2.5 acres. The images showed some roof damage in several rooms. The property was listed as "ready for renovations." The listing broker was Ramona A Romero-Brown with Platinum Realty Group (505-362-3667) and the buyers broker was Lidia Temple with Re/Max Exclusive. According to Ms. Robero-Brown this was a bank foreclosure and not suitable for market analysis. I also attempted to contact Ms. Temple, but was unable to leave a message. This home is 770 feet from the nearest panel.

The double wide home located at 4 Britton Road sold on April 23, 2021. The asking price was $275,000 for this 3 BR, 2 BA 2,034 square foot home on 5.05 acres. This home includes an attached garage as well as a 30x84 insulated shop building. The property is noted as completely renovated and with a modern kitchen. These unique features and recent updates make this a challenge to compare to other homes in the area. I spoke with Daniel Kniffin with the Kniffin Team, the listing broker (505-440-6878). He indicated that he received no negative feedback from the buyer or any of the parties that looked at this property related to the solar farm. He does not believe it had any impact on the marketing or the pricing of this home. I also spoke with Cheryl Marlow with Keller Williams Realty, the buyer's broker (505-238-3272), who also indicated that the solar farm had no impact on the sales price. This home is 1,700 feet from the nearest solar panel.

The double wide home located at 24 Griffin Road sold on September 19, 2022. The asking price was $239,900 for this 3 BR, 2 BA 1,680 s.f. home on 1.25 acres. This home includes stainless steel kitchen appliances, recent updates and a newly built detached garage. The property is noted as having many upgrades. The garage and upgrades make it challenging to use this for a paired sales analysis. I left a message with Billy Ringo, the listing broker, with Coldwell Banker Legacy (505-730-7382). I did connect with Katey Taylor Oueis with Berkshire Hathaway Home Services who indicated that the solar farm was not a concern for her buyer and had no impact on the purchase price. She further noted that it was a strange question and that she had never heard any concerns related to solar farms before. This home is 700 feet from the nearest panel. I have included an image from the listing below to show the view from the back of this house. The solar farm is on the right hand side of the photo running roughly parallel to the line of green grass in the neighbor's yard.

Roswell Solar, Roswell, Chaves County, NM

This 70 MW solar farm was built in 2016 at the same time as the adjoining Chaves Solar project. The closest adjoining home is 170 feet with numerous homes closer than 1,000 feet. I have provided the full breakdown of adjoining uses on the following page to show the parcels identified in the map above and the distance to each home. The average distance from panels to adjoining homes is 531 feet.

Surrounding Uses

#	MAP ID	Owner	GIS Data Acres	Present Use	Adjoin Acres	Adjoin Parcels	Distance (ft) Home/Panel
1	4139056439348000000	Notz	10.35	Residential	0.06%	2.17%	N/A
2	4139056508357000000	Dillard	4.77	Residential	0.03%	2.17%	522
3	4139056524407000000	Rocha	5.01	Residential	0.03%	2.17%	295
4	4139056524472000000	Eakin	5.03	Residential	0.03%	2.17%	275
5	4139057510035000000	Souza	6.45	Residential	0.04%	2.17%	570
6	4139057444037000000	Harkleroad	0.27	Residential	0.00%	2.17%	170
7	4139057500086000000	Blakeney	5.00	Residential	0.03%	2.17%	985
8	4139057500119000000	Degruchy	5.27	Residential	0.03%	2.17%	605
9	4139057501171000000	Degruchy	10.61	Residential	0.06%	2.17%	N/A
10	4139057502235000000	Ruiz	8.81	Residential	0.05%	2.17%	740
11	4139057480281000000	Sullins	0.67	Residential	0.00%	2.17%	N/A
12	4139057460282000000	Robertson	0.54	Residential	0.00%	2.17%	N/A
13	4139057445282000000	Robertson	0.76	Residential	0.00%	2.17%	N/A
14	4139057429283000000	Robertson	0.66	Residential	0.00%	2.17%	N/A
15	4139057414283000000	Robertson	0.55	Residential	0.00%	2.17%	N/A
16	4139057414301000000	Robertson	0.51	Residential	0.00%	2.17%	N/A
17	4139057414319000000	Robertson	0.51	Residential	0.00%	2.17%	N/A
18	4139057414336000000	Robertson	0.51	Residential	0.00%	2.17%	N/A
19	4139057414353000000	Robertson	0.51	Residential	0.00%	2.17%	N/A
20	4139057414370000000	Robertson	0.52	Residential	0.00%	2.17%	N/A
21	4139057415389000000	Robertson	0.63	Residential	0.00%	2.17%	N/A
22	4139057438420000000	Eakin	5.51	Residential	0.03%	2.17%	N/A
23	4139057418483000000	Ozbun	5.00	Residential	0.03%	2.17%	350
24	4139057442482000000	Waldrop	5.20	Residential	0.03%	2.17%	610
25	4139057498472000000	Dearing	12.72	Residential	0.07%	2.17%	N/A
26	4139057488500000000	Dearing	5.00	Residential	0.03%	2.17%	785
27	4144059402239000000	USA	15363.00	Agricultural	87.24%	2.17%	N/A
28	4140058033052000000	Southwestern	12.28	Utility	0.07%	2.17%	N/A
29	4140058034152000000	Waltmire	17.69	Residential	0.10%	2.17%	465
30	4140058036308000000	Chaves	29.80	Agricultural	0.17%	2.17%	N/A
31	4139058400414000000	Chaves	61.70	Agricultural	0.35%	2.17%	N/A
32	4139058217416000000	Chaves	20.10	Agricultural	0.11%	2.17%	N/A
33	4139058103395000000	Christman	42.73	Agricultural	0.24%	2.17%	N/A
34	4139058086248000000	Wilson	24.98	Agricultural	0.14%	2.17%	N/A
35	4139058085183000000	Wilson	24.93	Agricultural	0.14%	2.17%	N/A
36	4139058086117000000	Thibodeaux	24.87	Agricultural	0.14%	2.17%	N/A
37	4139058248047000000	Tenneson	5.00	Residential	0.03%	2.17%	N/A
38	4139058212049000000	Treadwell	5.00	Residential	0.03%	2.17%	N/A
39	4139058177050000000	Tabrez	5.00	Residential	0.03%	2.17%	N/A
40	4139058141052000000	Tabrez	5.00	Residential	0.03%	2.17%	N/A
41	413905810505300000	Tabrez	5.00	Residential	0.03%	2.17%	N/A
42	4139058069055000000	Plante	5.00	Residential	0.03%	2.17%	N/A
43	4139058031061000000	Mistry	5.00	Residential	0.03%	2.17%	N/A
44	4139058017039000000	Mistry	1.23	Residential	0.01%	2.17%	N/A
45	4139057019534000000	Eakin	19.27	Residential	0.11%	2.17%	N/A
46	4138056434431000000	L T Lewis	1831.56	Agricultural	10.40%	2.17%	N/A
		Total	**17610.503**		**100.00%**	**100.00%**	531

The home at 628 Wrangle Road sold on March 24, 2021. This single-family home built in 1990 with 3 BR, 2 BA, and 1,651 s.f. on 5.01 acres. Based on the listing information this property includes a sunroom, screened porch, raised & inground garden beds with drip irrigation, apple and pecan trees, chicken coops, 4 pens, covered trailer parking and a huge shop. I was unable to contact any broker involved in this sale. The closest solar panel to this home is 290 feet from this dwelling. The following images are from that listing and the solar panels are visible in the background just above the wooden gate on the right side of the first photo and similarly visible on the right side of the second photo.

The stacked poured concrete single-family home at 3687 E Pine Lodge Road sold on August 22, 2022. This property was listed for $275,000 for this 2 BR, 2 BA, 1,948 s.f. home built in 1998 on 5.20 acres. The home as a single car attached garage and oversized metal detached double car garage. I was unable to contact the brokers involved with this transaction. This home is about 600 feet from the nearest panel, but the nearest site line to the panels is around 700 feet.

The brick single-family home at 416 N Red Bridge Road sold on August 20, 2021. This property was listed for $369,000 for this 4 BR, 3 BA, 2,369 s.f. dwelling with an attached 2-car garage, detached workshop and garage built in 2005 on 5 acres. I was not able to contact the brokers involved with this transaction. This home is about 3,200 feet from the nearest solar panel.

Chaves Solar, Roswell, Chaves County, NM

This 70 MW solar farm was built in 2016 at the same time as the adjoining Roswell Solar farm noted above. The closest adjoining home is 205 feet from the nearest panel with numerous homes closer than 1,000 feet. The full breakdown of adjoining homes is shown on the next page. The average distance is 717 feet. Notably, there are a number of homes located between these two solar farms as shown on parcels 14-21 in the map above.

Surrounding Uses

#	MAP ID	Owner	GIS Data Acres	Present Use	Adjoin Acres	Adjoin Parcels	Distance (ft) Home/Panel
1	4144059402239000000	USA	15363.98	Agricultural	95.47%	4.76%	N/A
2	4140057307522000000	Clark	4.73	Residential	0.03%	4.76%	410
3	4144059402239000000	Clark	4.53	Residential	0.03%	4.76%	445
4	4140057418474000000	McTosh	4.76	Residential	0.03%	4.76%	525
5	4140058424036000000	Salazar	5.36	Residential	0.03%	4.76%	230
6	4140058426104000000	Alanis	5.28	Residential	0.03%	4.76%	205
7	4143061533504000000	Unknown	85.57	Agricultural	0.53%	4.76%	N/A
8	4141058181234000000	Elliot	10.01	Residential	0.06%	4.76%	N/A
9	4141058314392000000	Schellinger	140.00	Agricultural	0.87%	4.76%	N/A
10	4141058189507000000	Tatter	5.00	Residential	0.03%	4.76%	N/A
11	4140059513270000000	Clark	240.00	Agricultural	1.49%	4.76%	N/A
12	4140059229210000000	Chaves	39.52	Agricultural	0.25%	4.76%	N/A
13	4140059074135000000	Ward	80.00	Agricultural	0.50%	4.76%	N/A
14	4140058074514000000	Peterson	16.50	Residential	0.10%	4.76%	1,215
15	4140058073481000000	Barraza	5.00	Residential	0.03%	4.76%	N/A
16	4140058073440000000	Carreon	21.36	Agri/Res	0.13%	4.76%	1,865
17	4140058107375000000	Hernandez	9.99	Residential	0.06%	4.76%	1,100
18	4140058106309000000	Chaves	11.16	Utility	0.07%	4.76%	N/A
19	4140058107240000000	Waltmire	9.93	Residential	0.06%	4.76%	N/A
20	4140058105141000000	Waltmire	20.00	Residential	0.12%	4.76%	575
21	4140058103041000000	Cruz	9.81	Residential	0.06%	4.76%	600
		Total	**16092.491**		**100.00%**	**100.00%**	717

The double wide home at 73 Outlaw Trail sold on March 25, 2021. This property was listed for $230,000 for this 4 BR, 2 BA, 1,848 s.f. dwelling with a detached 3-car garage/workshop workshop built in 2000 on 10 acres. I was not able to contact the brokers involved with this transaction. This home is about 3,200 feet from the nearest solar panel. This home is 1,100 feet from the nearest panel at Chaves Solar and 1,100 feet from the nearest panel at Roswell Solar. The image below is from the listing and shows panels in the backround as can be seen to the left of the image.

VII. Market Analysis of the Impact on Value from Solar Farms

I have researched hundreds of solar farms in numerous states to determine the impact of these facilities on the value of adjoining property. This research has primarily been in North Carolina, but I have also conducted market impact analyses in New Mexico, Ohio, Virginia, South Carolina, Tennessee, Texas, Oregon, Mississippi, Maryland, New York, California, Missouri, Florida, Montana, Georgia, Louisiana, and New Jersey.

Wherever I have looked at solar farms, I have derived a breakdown of the adjoining uses to show what adjoining uses are typical for solar farms and what uses would likely be considered consistent with a solar farm use similar to the breakdown that I've shown for the subject property on the previous page. A summary showing the results of compiling that data over hundreds of solar farms is shown later in the Scope of Research section of this report.

I also consider whether the properties adjoining a solar farm in one location have characteristics similar to the properties abutting or adjoining the proposed site so that I can make an assessment of market impact on each proposed site. Notably, in most cases solar farms are placed in areas very similar to the site in question, which is surrounded by low density residential and agricultural uses. In my over 900 studies, I have found a striking repetition of that same typical adjoining use mix in over 90% of the solar farms I have looked at. Matched pair results in multiple states are strikingly similar, and all indicate that solar farms – which generate very little traffic, and do not generate noise, dust or have other harmful effects – do not negatively impact the value of adjoining or abutting properties.

In the prior section I focused on solar farms in New Mexico with discussion on sales adjoining solar farms.

On the following pages I have considered paired sales data in the Southwestern Region of the US with specific sales analysis in Texas, Arizona, and Colorado.

Following that data, I have included a brief summary of data pulled nationally as additional support for these findings.

A. Southwest Paired Sales Data

<u>1. Picture Rocks, Tucson, Pima County</u>

This solar farm was built in 2012 on a 302.80-acre tract but utilizing only 182 acres. This is a 20 MW facility with residential subdivision to the south and larger lot homes to the north, south and west.

I have identified two adjoining homes in the Tierra Linda subdivision that have sold recently in close proximity to the solar farm. They are written up as matched pairs below.

Adjoining Residential Sales After Solar Farm Approved

Parcel	Solar	Address	Acres	Date Sold	Sales Price	Built	GBA	$/GLA	BR/BA	Park	Style	Other
14	Adjoins	12986 W Moss V	0.97	6/4/2020	$393,900	2020	2,241	$175.77	4/3	3-Gar	Adobe	Crtyrd
	Not	13071 W Smr Ppy	0.85	2/26/2020	$389,409	2019	2,231	$174.54	4/3	3-Gar	Adobe	Crtyrd
	Not	13352 W Tgr Aloe	1.07	3/31/2020	$389,300	2015	2,555	$152.37	4/3	3-Gar	Adobe	Crtyrd
	Not		0.97	8/2/2020	$410,000	2018	2,688	$152.53	4/2	3-Gar	Adobe	Crtyrd

Adjoining Sales Adjusted

Time	Site	YB	GLA	BR/BA	Park	Other	Total	% Diff	Avg % Diff	Distance
							$393,900			1100
$3,249		$1,947	$1,396				$396,001	-1%		
$2,132		$9,733	-$38,275				$362,890	8%		
-$2,038		$4,100	-$54,545	$10,000			$367,517	7%		
									5%	

Adjoining Residential Sales After Solar Farm Approved

Parcel	Solar	Address	Acres	Date Sold	Sales Price	Built	GBA	$/GLA	BR/BA	Park	Style	Other
15	Adjoins	12986 W Moss V	1.00	6/27/2019	$350,000	2006	2,660	$131.58	4/3.5	3-Gar	Adobe	Crtyrd
	Not	12994 W Btr Bsh	0.92	5/24/2018	$302,000	2007	2,410	$125.31	4/3	3-Gar	Adobe	Crtyrd
	Not	12884W Zbra Aloe	0.83	1/29/2020	$336,500	2007	2,452	$137.23	4/3	3-Gar	Adobe	Crtyrd
	Not	12829W Smr Ppy	0.88	6/2/2020	$317,500	2006	2,452	$129.49	4/3	3-Gar	Adobe	Crtyrd

Adjoining Sales Adjusted									Avg	
Time	Site	YB	GLA	BR/BA	Park	Other	Total	% Diff	% Diff	Distance
							$350,000			970
$10,154		-$1,510	$25,062	$5,000			$340,707	3%		
-$6,125		-$1,683	$22,836	$5,000			$356,528	-2%		
-$9,124		$0	$21,546	$5,000			$334,923	4%		
									2%	

I have also looked at a recent sale of a manufactured home in close proximity to this solar farm for an additional matched pair. This home included a 2,200 s.f. detached metal building used as a garage/workshop that I adjusted based on Marshall Swift Cost Estimating Service values for a depreciated metal building.

Adjoining Residential Sales After Solar Farm Approved

Parcel	Solar	Address	Acres	Date Sold	Sales Price	Built	GBA	$/GLA	BR/BA	Park	Style	Other
9	Adjoins	12705 W Emigh	2.26	1/27/2019	$255,000	1994	2,640	$96.59	3/2	Det 4Car	Ranch	Horse
	Not	12715 W Emigh	2.50	5/30/2019	$210,000	2005	2,485	$84.51	4/2	Crprt	Ranch	Horse
	Not	12020 W Camper	1.81	9/15/2019	$200,000	2006	2,304	$86.81	4/2	Open	Ranch	Horse
	Not	12445 W Emigh	5.00	10/2/2018	$210,000	1999	2,400	$87.50	4/2	Open	Ranch	Horse

Adjoining Sales Adjusted									Avg	
Time	Site	YB	GLA	BR/BA	Park	Other	Total	% Diff	% Diff	Distance
							$255,000			990
-$2,177		-$11,550	$10,479		$46,000	$0	$252,752	1%		
-$3,893		-$12,000	$23,333		$50,000	$0	$257,440	-1%		
$2,071	-$25,000	-$5,250	$16,800		$50,000	$0	$248,621	3%		
									1%	

These matched pairs range from 970 to 1,100 feet from the closest solar panel and shows no negative impact due to proximity to the solar farm. The average measured impacts range from +1% to +5%, which is within a typical variation for real estate and supports a conclusion of no impact.

2. Avra Valley, Tucson, Pima County

This solar farm was built in 2013 on a 319.86-acre tract but utilizing only 246 acres. This is a 25 MW facility with residential uses to the west.

I have identified two sales of manufactured homes that are in close proximity to this solar farm and I have analyzed them as shown below.

Adjoining Residential Sales After Solar Farm Approved

Parcel	Solar	Address	Acres	Date Sold	Sales Price	Built	GBA	$/GLA	BR/BA	Park	Style
	Adjoins	9415 N Ghst Rnch	4.40	10/30/2018	$131,000	2004	1,508	$86.87	3/1.5	Det Gar	Manuf
	Not	8240 N Msq Oasis	20.01	2/16/2018	$145,000	2008	1,232	$117.69	3/1.5	Open	Manuf
	Not	7175 N Nlsn Quih.	5.00	3/26/2019	$136,000	2000	1,568	$86.73	3/2	Open	Manuf
	Not	5536 N Squeak	1.12	7/26/2018	$114,100	2003	1,512	$75.46	4/1.5	Open	Manuf

Adjoining Sales Adjusted

Time	Site	YB	GLA	BR/BA	Park	Other	Total	% Diff	Avg % Diff	Distance
							$131,000			1697
$3,128	-$31,000	-$2,900	$19,490		$3,000		$136,718	-4%		
-$1,685		$2,720	-$3,122	-$5,000	$3,000		$131,913	-1%		
$923	$5,000	$571	-$181		$3,000		$123,412	6%		
									0%	

Adjoining Residential Sales After Solar Farm Approved

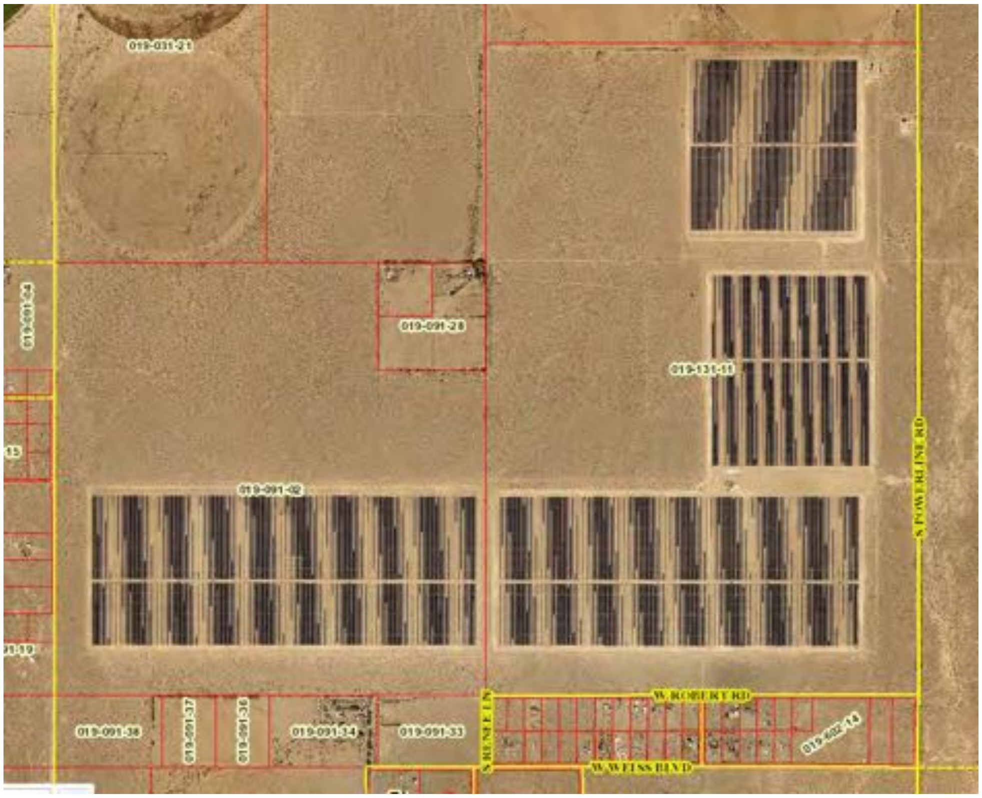
Parcel	Solar	Address	Acres	Date Sold	Sales Price	Built	GBA	$/GLA	BR/BA	Park	Style
	Adjoins	14441 W Stallion	4.40	12/21/2017	$150,000	2002	2,280	$65.79	3/3.5	Open	Manuf
	Not	9620 N Rng Bck	4.14	3/24/2019	$139,000	2003	2,026	$68.61	4/3	Open	Manuf
	Not	5537 N Whitetail	1.38	9/26/2018	$148,000	2006	2,037	$72.66	4/3	Open	Manuf
	Not	5494 N Puma	1.38	12/6/2017	$138,900	2000	2,044	$67.95	4/3	Open	Manuf

Adjoining Sales Adjusted

Time	Site	YB	GLA	BR/BA	Park	Other	Total	% Diff	Avg % Diff	Distance
							$150,000			1467
-$5,365		-$695	$10,456				$143,396	4%		
-$3,480	$5,000	-$2,960	$10,593				$157,154	-5%		
$176	$5,000	$1,389	$9,622				$155,087	-3%		
									-1%	

These matched pairs range from 1,467 to 1,697 feet from the closest solar panel and shows no negative impact due to proximity to the solar farm. The average measured impacts range from -1% to 0%, which is within a typical variation for real estate and supports a conclusion of no impact.

<u>3. Sunshine Valley Solar, Amargosa Valley, NV</u>



This solar farm was built in 2019 for a 104 MW facility with residential uses to the south. While this is in Nevada it is nearby and in a similar location and considered reasonable to compare to the solar farms in Arizona.

There was a recent 2020 sale of an adjoining property as shown below that is interesting in that it is the highest sales price in the Amargosa Valley area in the last five years that I could find. That in itself strongly suggests the solar farm had no impact on the sales price. I focused on other nearby sales in the same valley but not near the solar farm.

Adjoining Residential Sales After Solar Farm Approved

Parcel	Solar	Address	Acres	Date Sold	Sales Price	Built	GBA	$/GLA	BR/BA	Park	Style	Other
	Adjoins	887 W Roberts	1.90	8/16/2020	$200,000	2006	2,280	$87.72	4/2	Det 2G	Manuf	Horse
	Not	389 W Roberts	1.92	12/30/2018	$156,270	2006	2,272	$68.78	3/2.5	Det 2G	Manuf	Horse
	Not	3199 S Records	2.12	3/30/2018	$150,000	2002	1,568	$95.66	3/2	Det 3G	Manuf	Horse
	Not	4739 E Sage	5.00	4/9/2018	$175,000	1997	2,992	$58.49	4/3	Det 3G	Manuf	Horse

Adjoining Sales Adjusted

Time	Site	YB	GLA	BR/BA	Park	Other	Total	% Diff	Avg % Diff	Distance
							$200,000			1467
$7,835		$0	$330				$164,436	18%		
$10,997		$3,000	$40,867				$204,865	-2%		
$12,683		$7,875	-$24,987				$170,571	15%		
									10%	

4. Matched Pair – Alamo 2 Solar, Converse, Bexar County, TX

This project is located at 8203 Binz-Engleman Road, Converse, Texas, on 98.37 acres with a 4.4 MW output. This project is located with small lot residential development on to the north west and south. There appears to be minimal landscaping along this project. The closest home to the north is 83 feet from the solar panels, while the homes to the west are 110 feet and the homes to the south are 175 feet away from the solar panels.

This solar farm strongly shows an acceptance of nearby residential development in close proximity to solar farms as this solar farm has minimal landscaping, close proximity, small adjoining lot sizes, and the development of homes on three sides of the solar farm.

Adjoining Use Breakdown

Acreage	Parcels
Residential	94.64%
Agricultural	5.36%
Total	**100.00%**

I have considered home sales in the three adjoining subdivisions to look at matched pair data. There are sales and resales of homes in Glenloch and Mustang Valley subdivisions to the south and west of this solar farm.

I have considered multiple matched pairs from these subdivisions to show typical appreciation and no impact on property value both before and after the solar farm was constructed in 2013. I have looked at a number of home sales and resales in the larger subdivisions, but I have focused on those directly adjoining/facing the solar farm in the examples shown below. These are sales and resales of the homes adjoining the solar farm both before and after the solar farm project in 2013.

The comparables shown below are compared to an earlier sale prior to the solar farm announcement or construction followed by a second sale after the solar farm. The first two have solar farms in the Backyard (B), while the other has the solar farm in the Side yard (S). All of these sales show appreciation that falls within the typical annual appreciation for homes in this area over this time period.

	7703 Redstone Mnr (B)	
	Date	**Price**
Sale	10/3/2012	$149,980
Sale	3/24/2016	$166,000
	Time - YRS	**% Incr.**
	3.47	10.7%
	Per Year	**3.1%**
Years	3.5	**10.8%**

	7807 Redstone Mnr (B)	
	Date	**Price**
Sale	5/11/2012	$136,266
Sale	8/11/2014	$147,000
	Time - YRS	**% Incr.**
	2.25	7.9%
	Per Year	**3.5%**
Years	2.5	**8.7%**

	7734 Sundew Mist (S)	
	Date	**Price**
Sale	5/23/2012	$117,140
Sale	11/18/2014	$134,000
	Time - YRS	**% Incr.**
	2.49	14.4%
	Per Year	**5.8%**
Years	2	**11.6%**

I therefore conclude that this set of matched pairs shows no impact on property value and that homes in the area are showing typical appreciation consistent with other homes not in the vicinity of solar farms.

I have also considered a number of sales and resales of adjoining homes to look at appreciation adjoining the solar farm as compared to sales and resales of nearby homes not adjoining the solar farm. This provides for a good side-by-side comparison of appreciation in these areas.

The nearby sales not adjoining the solar farm shows an average annual increase of 3.85% per year increase with a range of 0.47% up to 8.34% and a median increase of 3.64%. The homes adjoining the solar farm shows an average annual increase of 4.48% per year with a range of 2.77% to 5.45% and a median of 5.21%. The increases adjoining the solar farm are actually higher than those nearby and strongly supports the assertion of no impact on property value.

Adjoining Residential Sales After Solar Farm Built											
Solar	**Address**	**Land (AC)**	**Date Sold**	**Sales Price**	**Built**	**GBA**	**$/GBA**	**BR/BA**	**Park**	**% Inc.**	**%/Yr**
Near	7926 Binson Court	0.13	7/20/2017	$184,000	2007	2,268	$81.13	4 bed	2 Gar		
Near	7926 Binson Court	0.13	11/27/2019	$199,999	2007	2,268	$88.18	4 bed	2 Gar	8.70%	3.69%
Near	7819 Caballo Canyon	0.10	9/7/2017	$135,500	2008	1,547	$87.59	3 bed	2 Gar		
Near	7819 Caballo Canyon	0.10	3/24/2020	$157,500	2008	1,547	$101.81	3 bed	2 Gar	16.24%	6.38%
Near	4730 Dapple Drive	0.13	10/7/2017	$154,900	2007	1,656	$93.54	3 bed	2 Gar		
Near	4730 Dapple Drive	0.13	6/11/2020	$170,000	2007	1,656	$102.66	3 bed	2 Gar	9.75%	3.64%
Near	4006 Giverny Ct	0.14	2/5/2018	$169,900	2007	1,656	$102.60	3 bed	2 Gar		
Near	4006 Giverny Ct	0.14	1/17/2020	$180,000	2007	1,656	$108.70	3 bed	2 Gar	5.94%	3.05%
Near	4003 Maston Manor	0.17	6/21/2018	$165,000	2010	1,544	$106.87	3 bed	2 Gar		
Near	4003 Maston Manor	0.17	2/14/2020	$173,400	2010	1,544	$112.31	3 bed	2 Gar	5.09%	3.08%
Near	4803 Pinto Creek	0.10	5/31/2018	$150,000	2007	1,547	$96.96	3 bed	2 Gar		
Near	4803 Pinto Creek	0.10	8/5/2020	$162,000	2007	1,547	$104.72	3 bed	2 Gar	8.00%	3.66%
Near	4303 Safe Harbor	0.09	1/14/2016	$162,574	2015	1,601	$101.55	3 bed	2 Gar		
Near	4303 Safe Harbor	0.09	3/26/2019	$165,000	2015	1,601	$103.06	3 bed	2 Gar	1.49%	0.47%
Near	4307 Safe Harbor	0.10	10/14/2016	$200,475	2016	2,488	$80.58	4 bed	2 Gar		
Near	4307 Safe Harbor	0.10	2/27/2020	$211,000	2016	2,488	$84.81	4 bed	2 Gar	5.25%	1.56%
Near	4338 Safe Harbor	0.09	5/5/2016	$149,900	2014	1,353	$110.79	3 bed	2 Gar		
Near	4338 Safe Harbor	0.09	7/10/2018	$159,000	2014	1,353	$117.52	3 bed	2 Gar	6.07%	2.78%
Near	7822 Sterling Manor	0.14	2/24/2017	$160,000	2011	1,898	$84.30	3 bed	2 Gar		
Near	7822 Sterling Manor	0.14	12/30/2019	$198,000	2011	1,898	$104.32	3 bed	2 Gar	23.75%	8.34%
Near	7938 Sterling Manor	0.15	7/29/2016	$157,000	2008	1,795	$87.47	3 bed	2 Gar		
Near	7938 Sterling Manor	0.15	7/31/2020	$192,500	2008	1,795	$107.24	3 bed	2 Gar	22.61%	5.64%
Adjacent	7731 Shining Glow	0.14	11/28/2018	$174,999	2006	2,658	$65.84	3 bed	2 Gar		
Adjacent	7731 Shining Glow	0.14	10/9/2020	$192,000	2006	2,658	$72.23	3 bed	2 Gar	9.71%	5.21%
Rear View	7935 Brinson Court	0.15	8/15/2017	$187,500	2007	2,328	$80.54	4 bed	2 Gar		
Rear View	7935 Brinson Court	0.15	1/10/2020	$200,000	2007	2,328	$85.91	4 bed	2 Gar	6.67%	2.77%
View	7815 Mustang Canyon	0.12	9/3/2016	$149,900	2009	2,267	$66.12	3 bed	2 Gar		
View	7815 Mustang Canyon	0.12	11/21/2018	$168,000	2009	2,267	$74.11	3 bed	2 Gar	12.07%	5.45%

I have also looked at these three recent sales that are either adjacent, have a rear view or a view of the solar farm. I have developed matched pairs for these homes as shown below.

Adjoining Residential Sales After Solar Farm Built

Solar	Address	Acres	Date Sold	Sales Price	Built	GBA	$/GLA	BR/BA	Park	Style
Nearby	7731 Shining Gl	0.14	10/9/2020	$192,000	2006	2,658	$72.23	3/2.5	2Gar	2-story
Not	7906 Caballo	0.13	10/2/2019	$201,000	2012	2,959	$67.93	4/2.5	2Gar	2-story
Not	4519 Rothberger	0.10	5/31/2020	$186,000	2006	2,773	$67.08	3/2.5	2Gar	2-story
Not	4530 Rothberger	0.10	9/8/2019	$167,500	2006	2,652	$63.16	3/2.5	2Gar	2-story

Adjoining Sales Adjusted

Address	Time	YB	GLA	BR/BA	Other	Total	% Diff	Avg % Diff	Distance
7731 Shining Gl						$192,000			210
7906 Caballo	$6,318	-$6,030	-$16,357			$184,931	4%		
4519 Rothberger	$2,053	$0	-$6,171			$181,882	5%		
4530 Rothberger	$5,604	$0	$303			$173,407	10%		
								6%	

Adjoining Residential Sales After Solar Farm Built

Solar	Address	Acres	Date Sold	Sales Price	Built	GBA	$/GLA	BR/BA	Park	Style
Adjoins	7935 Brinson	0.15	1/10/2020	$200,000	2007	2,328	$85.91	4/2.5	2Gar	2-Brick
Not	7926 Brinson	0.13	11/27/2019	$199,999	2007	2,268	$88.18	4/2.5	2Gar	2-Brick
Not	4015 Giverny	0.14	3/22/2018	$195,300	2007	2,328	$83.89	4/2.5	2Gar	2-Brick
Not	7935 Sterling	0.15	9/15/2019	$220,000	2011	2,512	$87.58	4/2.5	2Gar	2-Brick

Adjoining Sales Adjusted

Address	Time	YB	GLA	BR/BA	Other	Total	% Diff	Avg % Diff	Distance
7935 Brinson						$200,000			230
7926 Brinson	$742	$0	$4,233			$204,973	-2%		
4015 Giverny	$10,846	$0	$0			$206,146	-3%		
7935 Sterling	$2,169	-$4,400	-$12,892			$204,877	-2%		
								-3%	

Adjoining Residential Sales After Solar Farm Built

Solar	Address	Acres	Date Sold	Sales Price	Built	GBA	$/GLA	BR/BA	Park	Style
Adjoins	7815 Mustang	0.12	11/21/2018	$168,000	2009	2,267	$74.11	3/2.5	2Gar	2-story
Not	7635 Mustang M	0.10	4/21/2019	$149,500	2009	2,060	$72.57	3/2	2Gar	2-story
Not	5046 Mustang M	0.10	4/23/2018	$160,000	2010	2,147	$74.52	3/2.5	2Gar	2-story
Not	4431 Safe Harbor	0.10	9/17/2019	$165,000	2005	2,242	$73.60	4/2.5	2Gar	2-story

Adjoining Sales Adjusted

Address	Time	YB	GLA	BR/BA	Other	Total	% Diff	Avg % Diff	Distance
7815 Mustang						$168,000			200
7635 Mustang M	-$1,902	$0	$12,018	$5,000		$164,616	2%		
5046 Mustang M	$2,858	-$800	$7,154			$169,213	-1%		
4431 Safe Harbor	-$4,171	$3,300	$1,472			$165,601	1%		
								1%	

Adjoining Residential Sales After Solar Farm Built

Solar	Address	Acres	Date Sold	Sales Price	Built	GBA	$/GLA	BR/BA	Park	Style
Adjoins	7807 Mustang	0.14	11/8/2017	$162,000	2008	2,267	$71.46	3/2.5	2Gar	2-story
Not	7635 Mustang M	0.10	4/21/2019	$149,500	2009	2,060	$72.57	3/2	2Gar	2-story
Not	5046 Mustang M	0.10	4/23/2018	$160,000	2010	2,147	$74.52	3/2.5	2Gar	2-story
Not	4431 Safe Harbor	0.10	9/17/2019	$165,000	2005	2,242	$73.60	4/2.5	2Gar	2-story

Adjoining Sales Adjusted

Address	Time	YB	GLA	BR/BA	Other	Total	% Diff	Avg % Diff	Distance
7807 Mustang						$162,000			170
7635 Mustang M	-$6,665	-$748	$12,018	$5,000		$159,106	2%		
5046 Mustang M	-$2,238	-$1,600	$7,154			$163,316	-1%		
4431 Safe Harbor	-$9,427	$2,475	$1,472			$159,520	2%		
								1%	

Adjoining Residential Sales After Solar Farm Built

Solar	Address	Acres	Date Sold	Sales Price	Built	GBA	$/GLA	BR/BA	Park	Style
Adjoins	7734 Sundew M	0.14	6/12/2018	$158,400	2011	1,354	$116.99	3/2	2Gar	Ranch
Not	4338 Safe Hrbr	0.10	7/25/2019	$156,000	2014	1,413	$110.40	3/2	2Gar	Br Rnch
Not	7730 Palomino	0.10	4/23/2018	$154,000	2014	1,315	$117.11	3/2	2Gar	Br Rnch
Not	7907 Horse H	0.13	1/7/2018	$160,000	2012	1,420	$112.68	3/2	2Gar	Br Rnch

Adjoining Sales Adjusted

Address	Time	YB	GLA	BR/BA	Other	Total	% Diff	Avg % Diff	Distance
7734 Sundew M						$158,400			150
4338 Safe Hrbr	-$5,364	-$2,340	-$5,211			$143,085	10%		
7730 Palomino	$649	-$2,310	$3,654			$155,993	2%		
7907 Horse H	$2,103	-$800	-$5,949			$155,354	2%		
								4%	

Adjoining Residential Sales After Solar Farm Built

Solar	Address	Acres	Date Sold	Sales Price	Built	GBA	$/GLA	BR/BA	Park	Style	Other
Adjoins	7731 Stable V	0.11	9/9/2019	$189,900	2012	1,782	$106.57	3/2.5	2Gar	2-Brick	
Not	5026 Sunview	0.11	3/12/2020	$180,900	2013	1,782	$101.52	3/2.5	2Gar	2-Brick	Greenbelt
Not	5082 Mustang V	0.10	2/26/2020	$184,000	2013	2,013	$91.41	3/2.5	2Gar	2-Brick	
Not	4003 Matson M	0.17	2/17/2020	$173,400	2010	1,544	$112.31	3/2	2Gar	2-Brick	

Adjoining Sales Adjusted

Address	Time	YB	GLA	BR/BA	Other	Total	% Diff	Avg % Diff	Distance
7731 Stable V						$189,900			150
5026 Sunview	-$2,820	-$905	$0			$177,175	7%		
5082 Mustang V	-$2,636	-$920	-$16,892			$163,552	14%		
4003 Matson M	-$2,353	$1,734	$21,383			$194,164	-2%		
								6%	

The 6 matched pairs above provide a good indication of no impact for these homes adjoining the solar farm with all three having homes between 150 and 230 feet from the nearest solar panel.

The 6 matched pairs show a range of average impacts from -3% to +6% with an average of +3% and a median of +3%.

The best indicator for each matched pair is not the average, but the one requiring the least adjustment. In order this would be +5%, -2%, +1%, -1%, +2%, and +7% with an average of +2% and a median of +2%.

These data points strongly show no impact on property value due to the adjacency to the solar farm.

5. Matched Pair – Eddy II Solar, Eddy, Mclennan County, TX

This 10 MW project was built in 2017 and located on 93.24 acres with the closest home around 400 feet and that home adjoins the substation at the southeast corner of the facility.

I have considered a number of sales to the north on Anna Hobbs Lane and another sale on Hudson Lane as shown below.

Adjoining Residential Sales After Solar Farm Built

Solar	Address	Acres	Date Sold	Sales Price	Built	GBA	$/GLA	BR/BA	Park	Style	Other
Adjoins	341 Anna Hobbs	0.38	11/2/2017	$108,000	1982	1,436	$75.21	3/2	Gar	Br Rnch	
Not	715 W 3rd	0.29	6/9/2019	$116,613	1980	1,798	$64.86	3/2	Gr/Crpt	Ranch	
Not	506 4th	0.16	5/20/2019	$72,000	1957	1,307	$55.09	4/1.5	Det2Gr	Ranch	
Not	712 W 3rd	0.32	8/6/2018	$114,900	1985	1,689	$68.03	4/2	Open	Ranch	

Adjoining Sales Adjusted

	Time	YB	GLA	BR/BA	Park	Other	Total	% Diff	Avg % Diff	Distance
341 Anna Hobbs							$108,000			960
715 W 3rd	-$5,739	$1,166	-$18,783				$93,258	14%		
506 4th	-$3,422	$9,000	$5,685	$5,000			$88,263	18%		
712 W 3rd	-$2,682	-$1,724	-$13,769		$10,000		$106,725	1%		
									11%	

Adjoining Residential Sales After Solar Farm Built

Solar	Address	Acres	Date Sold	Sales Price	Built	GBA	$/GLA	BR/BA	Park	Style	Other
Adjoins	275 Anna Hobbs	0.38	2/14/2020	$160,000	1983	1,636	$97.80	3/2	Open	Br Rnch	
Not	112 Ashley	1.11	11/21/2019	$195,900	2006	1,526	$128.37	4/2	2Gar	Br Rnch	
Not	825 W 3rd	0.38	8/8/2018	$136,000	1978	1,300	$104.62	3/2	2Gar	Br Rnch	Updated
Not	813 W 3rd	0.38	6/19/2020	$158,250	1977	1,450	$109.14	3/2	2Gar	Br Rnch	Updated

Adjoining Sales Adjusted

	Time	YB	GLA	BR/BA	Park	Other	Total	% Diff	Avg % Diff	Distance
275 Anna Hobbs							$160,000			960
112 Ashley	$1,403	-$22,529	$11,297		-$15,000		$171,072	-7%		
825 W 3rd	$6,361	$3,400	$28,121		-$15,000		$158,881	1%		
813 W 3rd	-$1,680	$4,748	$16,240		-$15,000		$162,557	-2%		
									-3%	

Adjoining Residential Sales After Solar Farm Built

Solar	Address	Acres	Date Sold	Sales Price	Built	GBA	$/GLA	BR/BA	Park	Style	Other
Adjoins	205 Anna Hobbs	0.38	10/22/2018	$145,000	1981	1,636	$88.63	4/2	Gar	Br Rnch	
Not	112 Ashley	1.11	11/21/2019	$195,900	2006	1,526	$128.37	4/2	2Gar	Br Rnch	
Not	825 W 3rd	0.38	8/8/2018	$136,000	1978	1,300	$104.62	3/2	2Gar	Br Rnch	Updated
Not	813 W 3rd	0.38	6/19/2020	$158,250	1977	1,450	$109.14	3/2	2Gar	Br Rnch	Updated

Adjoining Sales Adjusted

	Time	YB	GLA	BR/BA	Park	Other	Total	% Diff	Avg % Diff	Distance
205 Anna Hobbs							$145,000			960
112 Ashley	-$6,521	-$24,488	$11,297		-$5,000		$171,189	-18%		
825 W 3rd	$860	$2,040	$28,121		-$5,000		$162,020	-12%		
813 W 3rd	-$8,081	$3,165	$16,240		-$5,000		$164,573	-13%		
									-14%	

I did not adjust the comparable sales above for the updates noted in the comparables as it is difficult to ascertain the extent of updates or the condition of the improvements at that point. I do note that the property was updated and put back on the market with a pending sale that I have shown in the adjustment below. After the updates this property is selling for $25,000 higher than the sale from just two years ago. I consider the pending sale to be more indicative of values in the area.

Adjoining Residential Sales After Solar Farm Built

Solar	Address	Acres	Date Sold	Sales Price	Built	GBA	$/GLA	BR/BA	Park	Style	Other
Adjoins	205 Anna Hobbs	0.38	Pending	$170,000	1981	1,636	$103.91	4/2	Gar	Br Rnch	Updated
Not	112 Ashley	1.11	11/21/2019	$195,900	2006	1,526	$128.37	4/2	2Gar	Br Rnch	
Not	825 W 3rd	0.38	8/8/2018	$136,000	1978	1,300	$104.62	3/2	2Gar	Br Rnch	Updated
Not	813 W 3rd	0.38	6/19/2020	$158,250	1977	1,450	$109.14	3/2	2Gar	Br Rnch	Updated

Adjoining Sales Adjusted

	Time	YB	GLA	BR/BA	Park	Other	Total	% Diff	Avg % Diff	Distance
205 Anna Hobbs							$170,000			960
112 Ashley	$5,745	-$24,488	$11,297		-$5,000		$183,454	-8%		
825 W 3rd	$9,375	$2,040	$28,121		-$5,000		$170,536	0%		
813 W 3rd	$1,827	$3,165	$16,240		-$5,000		$174,482	-3%		
									-4%	

Adjoining Residential Sales After Solar Farm Built

Solar	Address	Acres	Date Sold	Sales Price	Built	GBA	$/GLA	BR/BA	Park	Style	Other
Adjoins	189 Anna Hobbs	0.38	6/9/2018	$140,000	1976	1,276	$109.72	3/2	2Gar	Br Rnch	
Not	112 Ashley	1.11	11/21/2019	$195,900	2006	1,526	$128.37	4/2	2Gar	Br Rnch	
Not	825 W 3rd	0.38	8/8/2018	$136,000	1978	1,300	$104.62	3/2	2Gar	Br Rnch	Updated
Not	813 W 3rd	0.38	6/19/2020	$158,250	1977	1,450	$109.14	3/2	2Gar	Br Rnch	Updated

Adjoining Sales Adjusted

	Time	YB	GLA	BR/BA	Park	Other	Total	% Diff	Avg % Diff	Distance
189 Anna Hobbs							$140,000			960
112 Ashley	-$8,749	-$29,385	-$25,675				$132,091	6%		
825 W 3rd	-$688	-$1,360	-$2,009				$131,944	6%		
813 W 3rd	-$9,882	-$791	-$15,192				$132,385	5%		
									6%	

Adjoining Residential Sales After Solar Farm Built

Solar	Address	Acres	Date Sold	Sales Price	Built	GBA	$/GLA	BR/BA	Park	Style	Other
Adjoins	421 Hudson	5.00	3/12/2018	$326,531	2007	1,906	$171.32	4/2	2Gar	Br Rnch	Wrkshp
Not	743 Liberty Hill	10.00	5/6/2018	$317,000	1951	2,366	$133.98	4/2.5	Det2Gr	1.5 Story	Barn
Not	12608 Chapel	9.90	4/2/2018	$350,000	2009	1,888	$185.38	3/2	DetGar	Ranch	Barn/Apt
Not	130 Ralynn	1.00	4/23/2018	$339,600	2018	2,294	$148.04	4/3	3Gar	Br Rnch	

Adjoining Sales Adjusted

	Time	Site	YB	GLA	BR/BA	Park	Other	Total	% Diff	Avg % Diff	Distance
421 Hudson								$326,531			470
743 Liberty Hill	-$1,469	-$25,000	$88,760	-$49,305	-$5,000			$324,986	0%		
12608 Chapel	-$619	-$25,000	-$3,500	$2,669				$323,550	1%		
130 Ralynn	-$1,202	$15,000	-$18,678	-$45,951	-$10,000		$10,000	$288,769	12%		
										4%	

The 5 matched pairs above provide a good indication of no impact for these homes adjoining the solar farm. This excludes the first sale of 205 Anna Hobbs prior to the update as discussed above as the difference indicated in the first sale is clearly attributable to the lack of updating that home.

The 5 matched pairs show a range of average impacts from -4% to +11% with an average of +2.8% and a median of +4%.

The best indicator for each matched pair is not the average, but the one requiring the least adjustment. In order this would be +1%, -2%, -3%, +6%, and +1% with an average of +0.60% and a median of +1%.

These data points strongly show no impact on property value due to the adjacency to the solar farm.

6. Matched Pair – Somerset Solar, Somerset, Bexar County, TX

This 10.6 MW project has older and newer homes adjoining to the south and east as shown above.

I have considered a sale of two lots along W. Dixon Road that back up to the solar farm. These two lots total 2.4 acres and sold on August 13, 2020 for $75,000, or $37,500 per 1.2-acre lot.

A similar lot sold at 3750 FM 3175, Lytle, Texas on March 8, 2018 for $37,500 for a 1-acre lot. Another similar 1-acre lot at 40 Fair Oak, Somerset sold on March 31, 2019 for $40,000. I also looked at the July 8, 2018 sale of a 3.05-acre lot for $70,000. This size is very similar and likely could support two home sites similar to the W. Dixon Road land sale.

These lot sales show no negative impact due to the adjacent solar farm.

7. Grazing Yak Solar, Calhan, El Paso County, Colorado

This project is a 35 MW facility located on a 271.93-acre tract that was built in 2019. There are windmills nearby as can be seen on Parcel 5.

I have considered the sale of Parcel 7 (30945 Washington Road, Calhan, CO) shown above which includes an older dwelling that is only 660 feet from the nearest solar panel. This property includes 46.09 acres and the dwelling was in poor condition. I spoke with Jody Heffner the broker who sold this tract who indicated that the solar farm had no impact on the purchase price and the nearby windfarm likewise had no impact. The home was difficult to compare to other homes in the area given the small size and condition.

Properties needing significant repairs are difficult to use in a paired sales analysis without good estimates of the needed repairs. I have therefore not attempted a paired sales analysis, but I have relied on the broker's comments related to the solar farm having no impact on the sales price.

8. San Luis Valley Solar, Hooper, Alamosa County, Colorado

This project was built in 2010 and located on a portion of a 308-acre tract for a 35 MW with the closest home at 620 feet from the closest solar panel.

I considered the current listing of Parcel 10 (8120 N County Road 106, Mosca, CO) that is 620 feet from the closest solar panel. This property has not sold and has been on the market for 40 days as of this writing. I spoke with Bill Werner with Werner Realty who is marketing this 1,546 s.f. home on 4.61 acres. He indicated that the adjoining solar farm was having no impact on the marketing price or the marketing time on the project. He indicated that there were few homes in the area to choose from, which also makes it difficult to do a paired sales analysis on this asking price.

As this has not sold, I cannot do a paired sales analysis, but I have relied on the brokers comments in this analysis.

9. SR Jenkins Fort Lupton, Fort Lupton, Weld County, Colorado

This project is a 13 MW facility located on a 141.89-acre tract that was built in 2016.

I have considered the 2020 sale of Parcel 5 (16230 Highway 52, Lupton, CO) as shown above. The home on this parcel is 525 feet from the closest solar panel. This was a 29.47-acre tract with a single-family home, detached small office building, and various agricultural buildings. The collection of buildings and acreage is very unique, which limits the reliability of any paired sales analysis on this transfer.

I spoke with Lisa Moen, the buyer's realtor, who indicated that the solar farm was not a concern at all for the buyer. She further noted that the buyer was her Mother-In-Law and that the solar farm has been a quiet neighbor and is still not a concern for the buyer. Ms. Moen further indicated that it would be difficult to compare this sale to other properties in the area due to the unique assemblage of buildings on the property.

So I have not completed a paired sales analysis on this sale either, but I have considered the comments by the broker in this analysis.

Conclusion – Southwest

Matched Pair Summary							Adj. Uses By Acreage				1 mile Radius (2020-2022 Data)		
	Name	City	State	Acres	MW	Topo Shift	Res	Ag	Ag/Res	Com/Ind	Population	Med. Income	Avg. Housing Unit
1	Picture Rocks	Tucson	AZ	182	20.00	N/A	6%	88%	6%	0%	102	$81,081	$280,172
2	Avra Valley	Tucson	AZ	246	25.00	N/A	3%	94%	3%	0%	85	$80,997	$292,308
3	Sunshine	Amargosa	NV	N/A	104.00	N/A	N/A	N/A	N/A	N/A	42	$50,000	$106,250
4	Alamo II	Converse	TX	98	4.40	30	95%	5%	0%	0%	9,257	$62,363	$138,617
5	Eddy II	Eddy	TX	93	10.00	N/A	15%	25%	58%	2%	551	$59,627	$139,088
6	Somerset	Somerset	TX	128	10.60	N/A	5%	95%	0%	0%	1,293	$41,574	$135,490
7	Grazing Yak	Calhan	CO	272	35.00	N/A	0%	97%	3%	0%	41	$80,127	$458,929
8	San Luis Vly	Hooper	CO	308	35.00	N/A	5%	95%	0%	0%	12	$60,000	$91,667
9	SR Jenkins	Ft Lupton	CO	142	13.00	N/A	2%	90%	8%	0%	134	$90,326	$510,135
	Average			184	28.56	30	16%	74%	10%	0%	1,280	$67,344	$239,184
	Median			162	20.00	30	5%	92%	3%	0%	102	$62,363	$139,088
	High			308	104.00	30	95%	97%	58%	2%	9,257	$90,326	$510,135
	Low			93	4.40	30	0%	5%	0%	0%	12	$41,574	$91,667

The median income for the population within 1 mile of a solar farm for this set of data is $62,363 with a median housing unit value of $139,088. All of these comparable solar farms have homes within a 1-mile radius under $520,000 on average, though I have matched pairs in other states over $1,000,000 in price adjoining large solar farms. The adjoining uses show that residential and agricultural uses are the predominant adjoining uses.

Based on the similarity of adjoining uses and demographic data between these sites and the subject property, I consider it reasonable to compare these sites to the subject property. These solar farms include solar farms up to 104 MW in size.

Each of these solar farms has adjoining home sales that support a conclusion of no impact on adjoining property values.

I note that real estate is an imperfect market and both market imperfection and typical market variations commonly support a +/- 5% difference in real estate. Essentially, two identical homes sitting next to each other being sold by different sellers to different buyers will almost never sell for the exact same price. So minor differences are not indications of positive or negative shifts in the market, but just indications of typical market variation. For this reason, I consider indicators of +/- 5% to be indications of no impact on property value.

In the charts that follow I have only included the data where I completed a paired sales to exclude sales that only have broker comments.

Therefore, there are 20 identified sales adjoining solar farms that are in the chart. While some subsets of data I have in other states do show some results with negative impacts on property value, none of the data in this subset indicates a negative impact on value. There are 4 of the 20 matched pairs that suggest a positive impact due to the solar farm (impacts between +6% and +18%). That leaves 16 out of 20, or 80% of the findings supporting no impact on value. The biggest positive impact identified is just an outlier as there were few comparables in that market with which to compare and I do not put much weight on that large positive impact on value.

The aggregate of all of these differences is +2% on average and +1% on median, which strongly supports a finding of no impact on property value and not an enhancement on property value.

The following pages show greater detail on these solar farms and how the 20 matched pairs from these solar farms were established. Below I have shown those findings charted from smallest to largest to show that most of the findings are between +/-5% within typical market variation.


Breakdown of findings
20%
15%
10%
5%
0%
-5%
paired Sale Impact
0
5
10
15
20
25
Individual Paired Sales in Order of Difference Identified

Residential Dwelling Matched Pairs Adjoining Solar Farms

Pair	Solar Farm	City	State	MW	Approx Distance	Tax ID/Address	Date	Sale Price	Adj. Sale Price	% Diff	Veg. Buffer
1	Alamo II	San Antonio	TX	4.4	360	7703 Redstone Mnr	Mar-16	$166,000			Light
						7703 Redstone Mnr	Oct-12	$149,980	$165,728	0%	
2	Alamo II	San Antonio	TX	4.4	170	7807 Redstone Mnr	Aug-14	$147,000			Light
						7807 Redstone Mnr	May-12	$136,266	$145,464	1%	
3	Alamo II	San Antonio	TX	4.4	150	7734 Sundew Mist	Nov-14	$134,000			Light
						7734 Sundew Mist	May-12	$117,140	$125,928	6%	
4	Picture Rocks	Tucson	AZ	20	1100	12980 W Moss V	Jun-20	$393,900			None
						13071 W Smr Poppy	Feb-20	$389,409	$396,001	-1%	
5	Picture Rocks	Tucson	AZ	20	970	12986 W Moss V	Jun-19	$350,000			None
						12884 W Zebra Aloe	Jan-20	$336,500	$356,528	-2%	
6	Picture Rocks	Tucson	AZ	20	990	12705 W Emigh	Jan-19	$255,000			None
						12020 W Camper	Sep-19	$200,000	$257,440	-1%	
7	Avra Valley	Tucson	AZ	25	1697	9415 N Ghost Ranch	Oct-18	$131,000			None
						7175 N Nelson Quich	Mar-19	$136,000	$131,913	-1%	
8	Avra Valley	Tucson	AZ	25	1467	14441 W Stallion	Dec-17	$150,000			None
						9620 N Rng Bck	Mar-19	$139,000	$143,396	4%	
9	Alamo 2	Converse	TX	4.4	210	7731 Shining Gl	Oct-20	$192,000			Light
						4519 Rothberger	May-20	$186,000	$181,882	5%	
10	Alamo 2	Converse	TX	4.4	230	7935 Brinson	Jan-20	$200,000			Light
						2926 Brinson	Nov-19	$199,999	$204,973	-2%	
11	Alamo 2	Converse	TX	4.4	200	7815 Mustang	Nov-18	$168,000			Light
						4431 Safe Harbor	Sep-19	$165,000	$165,601	1%	
12	Alamo 2	Converse	TX	4.4	170	7807 Mustang	Nov-17	$162,000			Light
						5046 Mustang	Apr-18	$160,000	$163,316	-1%	
13	Alamo 2	Converse	TX	4.4	150	7734 Sundew Mist	Jun-18	$158,400			Light
						7730 Palomino	Apr-18	$154,000	$155,993	2%	
14	Alamo 2	Converse	TX	4.4	150	7731 Stable View	Sep-19	$189,900			Light
						5026 Sunview	Mar-20	$180,900	$177,175	7%	
15	Eddy II	Eddy	TX	10	960	341 Anna Hobbs	Nov-17	$108,000			Light
						712 W 3rd	Aug-18	$114,900	$106,725	1%	
16	Eddy II	Eddy	TX	10	960	275 Anna Hobbs	Feb-20	$160,000			Light
						813 W 3rd	Jun-20	$158,250	$162,557	-2%	
17	Eddy II	Eddy	TX	10	960	205 Anna Hobbs	Pending	$170,000			Light
						813 W 3rd	Jun-20	$158,250	$174,482	-3%	
18	Eddy II	Eddy	TX	10	960	189 Anna Hobbs	Jun-18	$140,000			Light
						825 W 3rd	Aug-18	$136,000	$131,944	6%	
19	Eddy II	Eddy	TX	10	470	421 Hudson	Mar-18	$326,531			Light
						12608 Chapel	Apr-18	$350,000	$323,550	1%	
20	Sunshine	Amargosa	NV	104	1467	887 W Rogers	Aug-20	$200,000			None
						389 W Rogers	Dec-18	$156,270	$164,436	18%	

MW	Avg. Distance
15.18	690
10.00	715
104.00	1,697
4.40	150

	Indicated Impact
Average	2%
Median	1%
High	18%
Low	-3%

B. Summary of National Data on Solar Farms

I have worked in numerous states related to solar farms and I have been tracking matched pairs in most of those states. On the following pages I provide a brief summary of those findings showing 38 solar farms over 5 MW studied with each one providing pair sale data supporting the findings of this report.

The solar farms summary is shown below with a summary of the matched pair data shown on the following page.

Matched Pair Summary							**Adj. Uses By Acreage**				**1 mile Radius (2010-2020 Data)**			
						Topo						**Med.**	**Avg. Housing**	
	Name	**City**	**State**	**Acres**	**MW**	**Shift**	**Res**	**Ag**	**Ag/Res**	**Com/Ind**	**Population**	**Income**	**Unit**	**Veg. Buffer**
1	AM Best	Goldsboro	NC	38	5.00	2	38%	0%	23%	39%	1,523	$37,358	$148,375	Light
2	Mulberry	Selmer	TN	160	5.00	60	13%	73%	10%	3%	467	$40,936	$171,746	Lt to Med
3	Leonard	Hughesville	MD	47	5.00	20	18%	75%	0%	6%	525	$106,550	$350,000	Light
4	Gastonia SC	Gastonia	NC	35	5.00	48	33%	0%	23%	44%	4,689	$35,057	$126,562	Light
5	Summit	Moyock	NC	2,034	80.00	4	4%	0%	94%	2%	382	$79,114	$281,731	Light
7	Tracy	Bailey	NC	50	5.00	10	29%	0%	71%	0%	312	$43,940	$99,219	Heavy
8	Manatee	Parrish	FL	1,180	75.00	20	2%	97%	1%	0%	48	$75,000	$291,667	Heavy
9	McBride	Midland	NC	627	75.00	140	12%	10%	78%	0%	398	$63,678	$256,306	Lt to Med
10	Grand Ridge	Streator	IL	160	20.00	1	8%	87%	5%	0%	96	$70,158	$187,037	Light
11	Dominion	Indianapolis	IN	134	8.60	20	3%	97%	0%	0%	3,774	$61,115	$167,515	Light
12	Mariposa	Stanley	NC	36	5.00	96	48%	0%	52%	0%	1,716	$36,439	$137,884	Light
13	Clarke Cnty	White Post	VA	234	20.00	70	14%	39%	46%	1%	578	$81,022	$374,453	Light
14	Flemington	Flemington	NJ	120	9.36	N/A	13%	50%	28%	8%	3,477	$105,714	$444,696	Lt to Med
15	Frenchtown	Frenchtown	NJ	139	7.90	N/A	37%	35%	29%	0%	457	$111,562	$515,399	Light
16	McGraw	East Windsor	NJ	95	14.00	N/A	27%	44%	0%	29%	7,684	$78,417	$362,428	Light
17	Tinton Falls	Tinton Falls	NJ	100	16.00	N/A	98%	0%	0%	2%	4,667	$92,346	$343,492	Light
18	Simon	Social Circle	GA	237	30.00	71	1%	63%	36%	0%	203	$76,155	$269,922	Medium
19	Candace	Princeton	NC	54	5.00	22	76%	24%	0%	0%	448	$51,002	$107,171	Medium
20	Walker	Barhamsville	VA	485	20.00	N/A	12%	68%	20%	0%	203	$80,773	$320,076	Light
21	Innov 46	Hope Mills	NC	532	78.50	0	17%	83%	0%	0%	2,247	$58,688	$183,435	Light
22	Innov 42	Fayetteville	NC	414	71.00	0	41%	59%	0%	0%	568	$60,037	$276,347	Light
23	Demille	Lapeer	MI	160	28.40	10	10%	68%	0%	22%	2,010	$47,208	$187,214	Light
24	Turrill	Lapeer	MI	230	19.60	10	75%	59%	0%	25%	2,390	$46,839	$110,361	Light
25	Sunfish	Willow Spring	NC	50	6.40	30	35%	35%	30%	0%	1,515	$63,652	$253,138	Light
26	Picture Rocks	Tucson	AZ	182	20.00	N/A	6%	88%	6%	0%	102	$81,081	$280,172	None
27	Avra Valley	Tucson	AZ	246	25.00	N/A	3%	94%	3%	0%	85	$80,997	$292,308	None
28	Sappony	Stony Crk	VA	322	20.00	N/A	2%	98%	0%	0%	74	$51,410	$155,208	Medium
29	Camden Dam	Camden	NC	50	5.00	0	17%	72%	11%	0%	403	$84,426	$230,288	Light
30	Grandy	Grandy	NC	121	20.00	10	55%	24%	0%	21%	949	$50,355	$231,408	Light
31	Champion	Pelion	SC	100	10.00	N/A	4%	70%	8%	18%	1,336	$46,867	$171,939	Light
32	Eddy II	Eddy	TX	93	10.00	N/A	15%	25%	58%	2%	551	$59,627	$139,088	Light
33	Somerset	Somerset	TX	128	10.60	N/A	5%	95%	0%	0%	1,293	$41,574	$135,490	Light
34	DG Amp Piqua	Piqua	OH	86	12.60	2	26%	16%	58%	0%	6,735	$38,919	$96,555	Light
45	Barefoot Bay	Barefoot Bay	FL	504	74.50	0	11%	87%	0%	3%	2,446	$36,737	$143,320	Lt to Med
36	Miami-Dade	Miami	FL	347	74.50	0	26%	74%	0%	0%	127	$90,909	$403,571	Light
37	Spotyslvania	Paytes	VA	3,500	617.00	160	37%	52%	11%	0%	74	$120,861	$483,333	Med to Hvy
38	Anderson 3&4	Anderson	IN	104	22.00	N/A	N/A	N/A	N/A	N/A	1,968	$45,901	$124,663	Light
	Average			355	41.51	32	24%	52%	19%	6%	1,528	$65,741	$239,284	
	Median			139	19.60	10	16%	59%	7%	0%	568	$61,115	$230,288	
	High			3,500	617.00	160	98%	98%	94%	44%	7,684	$120,861	$515,399	
	Low			35	5.00	0	1%	0%	0%	0%	48	$35,057	$96,555	

From these 38 solar farms, I have derived 98 matched pairs. The matched pairs/paired sales show no negative impact at distances as close as 105 feet between a solar panel and the nearest point on a home. The range of impacts is -10% to +10% with an average and median of +1%.

	MW	Avg. Distance	Indicated Impact	% Dif
Average	44.35	559	**Average**	1%
Median	14.00	400	**Median**	1%
High	617.00	2,020	**High**	10%
Low	2.60	105	**Low**	-10%

While the range is broad, the two charts below show the data points in range from lowest to highest. There are only 3 data points out of 98 that show a negative impact (3% of the data). There are 10 data points out of 98 that show a positive impact (10% of the data). The rest of the data points (87%) support a finding of no impact due to adjacency to a solar farm. This works out to 95 out of 98 data points supporting a finding of no impact or a positive impact or 97% of the data.

As discussed earlier in this report, I consider this data to strongly support a finding of no impact on value as most of the findings are within typical market variation and even within that, most are mildly positive findings.

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C. Larger Solar Farms

I have also considered larger solar farms to address impacts related to larger projects. Projects have been increasing in size and most of the projects between 100 and 1000 MW are newer with little time for adjoining sales. I have included a breakdown of solar farms with 20 MW to 80 MW facilities with one 617 MW facility.

Matched Pair Summary - @20 MW And Larger

						Topo	Adj. Uses By Acreage				1 mile Radius (2010-2019 Data)	Med.	Avg. Housing	Veg.
	Name	City	State	Acres	MW	Shift	Res	Ag	Ag/Res	Com/Ind	Popl.	Income	Unit	Buffer
1	Summit	Moyock	NC	2,034	80.00	4	4%	0%	94%	2%	382	$79,114	$281,731	Light
2	Manatee	Parrish	FL	1,180	75.00	20	2%	97%	1%	0%	48	$75,000	$291,667	Heavy
3	McBride	Midland	NC	627	75.00	140	12%	10%	78%	0%	398	$63,678	$256,306	Lt to Med
4	Grand Ridge	Streator	IL	160	20.00	1	8%	87%	5%	0%	96	$70,158	$187,037	Light
5	Clarke Cnty	White Post	VA	234	20.00	70	14%	39%	46%	1%	578	$81,022	$374,453	Light
6	Simon	Social Circle	GA	237	30.00	71	1%	63%	36%	0%	203	$76,155	$269,922	Medium
7	Walker	Barhamsville	VA	485	20.00	N/A	12%	68%	20%	0%	203	$80,773	$320,076	Light
8	Innov 46	Hope Mills	NC	532	78.50	0	17%	83%	0%	0%	2,247	$58,688	$183,435	Light
9	Innov 42	Fayetteville	NC	414	71.00	0	41%	59%	0%	0%	568	$60,037	$276,347	Light
10	Demille	Lapeer	MI	160	28.40	10	10%	68%	0%	22%	2,010	$47,208	$187,214	Light
11	Turrill	Lapeer	MI	230	19.60	10	75%	59%	0%	25%	2,390	$46,839	$110,361	Light
12	Picure Rocks	Tucson	AZ	182	20.00	N/A	6%	88%	6%	0%	102	$81,081	$280,172	Light
13	Avra Valley	Tucson	AZ	246	25.00	N/A	3%	94%	3%	0%	85	$80,997	$292,308	None
14	Sappony	Stony Crk	VA	322	20.00	N/A	2%	98%	0%	0%	74	$51,410	$155,208	None
15	Grandy	Grandy	NC	121	20.00	10	55%	24%	0%	21%	949	$50,355	$231,408	Medium
16	Barefoot Bay	Barefoot Bay	FL	504	74.50	0	11%	87%	0%	3%	2,446	$36,737	$143,320	Lt to Med
17	Miami-Dade	Miami	FL	347	74.50	0	26%	74%	0%	0%	127	$90,909	$403,571	Light
18	Spotyslvania	Paytes	VA	3,500	617.00	160	37%	52%	11%	0%	74	$120,861	$483,333	Med to Hvy
	Average			640	76.03		19%	64%	17%	4%	721	$69,501	$262,659	
	Median			335	29.20		12%	68%	2%	0%	293	$72,579	$273,135	
	High			3,500	617.00		75%	98%	94%	25%	2,446	$120,861	$483,333	
	Low			121	19.60		1%	0%	0%	0%	48	$36,737	$110,361	

The breakdown of adjoining uses, population density, median income and housing prices for these projects are very similar to those of the larger set. The matched pairs for each of these were considered earlier and support a finding of no negative impact on the adjoining home values.

I have included a breakdown of solar farms with 50 MW to 617 MW facilities adjoining.

Matched Pair Summary - @50 MW And Larger

						Topo	Adj. Uses By Acreage				1 mile Radius (2010-2019 Data)	Med.	Avg. Housing	Veg.
	Name	City	State	Acres	MW	Shift	Res	Ag	Ag/Res	Com/Ind	Popl.	Income	Unit	Buffer
1	Summit	Moyock	NC	2,034	80.00	4	4%	0%	94%	2%	382	$79,114	$281,731	Light
2	Manatee	Parrish	FL	1,180	75.00	20	2%	97%	1%	0%	48	$75,000	$291,667	Heavy
3	McBride	Midland	NC	627	75.00	140	12%	10%	78%	0%	398	$63,678	$256,306	Lt to Med
4	Innov 46	Hope Mills	NC	532	78.50	0	17%	83%	0%	0%	2,247	$58,688	$183,435	Light
5	Innov 42	Fayetteville	NC	414	71.00	0	41%	59%	0%	0%	568	$60,037	$276,347	Light
6	Barefoot Bay	Barefoot Bay	FL	504	74.50	0	11%	87%	0%	3%	2,446	$36,737	$143,320	Lt to Med
7	Miami-Dade	Miami	FL	347	74.50	0	26%	74%	0%	0%	127	$90,909	$403,571	Light
8	Spotyslvania	Paytes	VA	3,500	617.00	160	37%	52%	11%	0%	74	$120,861	$483,333	Med to Hvy
	Average			1,142	143.19		19%	58%	23%	1%	786	$73,128	$289,964	
	Median			580	75.00		15%	67%	0%	0%	390	$69,339	$279,039	
	High			3,500	617.00		41%	97%	94%	3%	2,446	$120,861	$483,333	
	Low			347	71.00		2%	0%	0%	0%	48	$36,737	$143,320	

The breakdown of adjoining uses, population density, median income and housing prices for these projects are very similar to those of the larger set. The matched pairs for each of these were considered earlier and support a finding of no negative impact on the adjoining home values.

The data for these larger solar farms is shown in the SE USA and the National data breakdowns with similar landscaping, setbacks and range of impacts that fall mostly in the +/-5% range as can be seen earlier in this report.

On the following page I show 81 projects ranging in size from 50 MW up to 1,000 MW with an average size of 111.80 MW and a median of 80 MW. The average closest distance for an adjoining home is 263 feet, while the median distance is 188 feet. The closest distance is 57 feet. The mix of adjoining uses is similar with most of the adjoining uses remaining residential or agricultural in nature. This is the list of solar farms that I have researched for possible matched pairs and not a complete list of larger solar farms in those states.

Parcel #	State	City	Name	Output (MW)	Total Acres	Used Acres	Avg. Dist to home	Closest Home	Adjoining Use by Acre Res	Agri	Ag/R	Com
78	NC	Moyock	Summit/Ranchland	80	2034		674	360	4%	94%	0%	2%
133	MS	Hattiesburg	Hattiesburg	50	1129	479.6	650	315	35%	65%	0%	0%
179	SC	Ridgeland	Jasper	140	1600	1000	461	108	2%	85%	13%	0%
211	NC	Enfield	Chestnut	75	1428.1		1,429	210	4%	96%	0%	0%
222	VA	Chase City	Grasshopper	80	946.25				6%	87%	5%	1%
226	VA	Louisa	Belcher	88	1238.1			150	19%	53%	28%	0%
305	FL	Dade City	Mountain View	55	347.12		510	175	32%	39%	21%	8%
319	FL	Jasper	Hamilton	74.9	1268.9	537	3,596	240	5%	67%	28%	0%
336	FL	Parrish	Manatee	74.5	1180.4		1,079	625	2%	50%	1%	47%
337	FL	Arcadia	Citrus	74.5	640				0%	0%	100%	0%
338	FL	Port Charlotte	Babcock	74.5	422.61				0%	0%	100%	0%
353	VA	Oak Hall	Amazon East(ern sh	80	1000		645	135	8%	75%	17%	0%
364	VA	Stevensburg	Greenwood	100	2266.6	1800	788	200	8%	62%	29%	0%
368	NC	Warsaw	Warsaw	87.5	585.97	499	526	130	11%	66%	21%	3%
390	NC	Ellerbe	Innovative Solar 34	50	385.24	226	N/A	N/A	1%	99%	0%	0%
399	NC	Midland	McBride	74.9	974.59	627	1,425	140	12%	78%	9%	0%
400	FL	Mulberry	Alafia	51	420.35		490	105	7%	90%	3%	0%
406	VA	Clover	Foxhound	91	1311.8		885	185	5%	61%	17%	18%
410	FL	Trenton	Trenton	74.5	480		2,193	775	0%	26%	55%	19%
411	NC	Battleboro	Fern	100	1235.4	960.71	1,494	220	5%	76%	19%	0%
412	MD	Goldsboro	Cherrywood	202	1722.9	1073.7	429	200	10%	76%	13%	0%
434	NC	Conetoe	Conetoe	80	1389.9	910.6	1,152	120	5%	78%	17%	0%
440	FL	Debary	Debary	74.5	844.63		654	190	3%	27%	0%	70%
441	FL	Hawthorne	Horizon	74.5	684				3%	81%	16%	0%
484	VA	Newsoms	Southampton	100	3243.9		-	-	3%	78%	17%	3%
486	VA	Stuarts Draft	Augusta	125	3197.4	1147	588	165	16%	61%	16%	7%
491	NC	Misenheimer	Misenheimer 2018	80	740.2	687.2	504	130	11%	40%	22%	27%
494	VA	Shacklefords	Walnut	110	1700	1173	641	165	14%	72%	13%	1%
496	VA	Clover	Piney Creek	80	776.18	422	523	195	15%	62%	24%	0%
511	NC	Scotland Neck	American Beech	160	3255.2	1807.8	1,262	205	2%	58%	38%	3%
514	NC	Reidsville	Williamsburg	80	802.6	507	734	200	25%	12%	63%	0%
517	VA	Luray	Cape	100	566.53	461	519	110	42%	12%	46%	0%
518	VA	Emporia	Fountain Creek	80	798.3	595	862	300	6%	23%	71%	0%
525	NC	Plymouth	Macadamia	484	5578.7	4813.5	1,513	275	1%	90%	9%	0%
526	NC	Mooresboro	Broad River	50	759.8	365	419	70	29%	55%	16%	0%
555	FL	Mulberry	Durrance	74.5	463.57	324.65	438	140	3%	97%	0%	0%
560	NC	Yadkinville	Sugar	60	477	357	382	65	19%	39%	20%	22%
561	NC	Enfield	Halifax 80mw 2019	80	1007.6	1007.6	672	190	8%	73%	19%	0%
577	VA	Windsor	Windsor	85	564.1	564.1	572	160	9%	67%	24%	0%
579	VA	Paytes	Spotsylvania	500	6412	3500			9%	52%	11%	27%
582	NC	Salisbury	China Grove	65	428.66	324.26	438	85	58%	4%	38%	0%
583	NC	Walnut Cove	Lick Creek	50	1424	185.11	410	65	20%	64%	11%	5%
584	NC	Enfield	Sweetleaf	94	1956.3	1250	968	160	5%	63%	32%	0%
586	VA	Aylett	Sweet Sue	77	1262	576	1,617	680	7%	68%	25%	0%
593	NC	Windsor	Sumac	120	3360.6	1257.9	876	160	4%	90%	6%	0%
599	TN	Somerville	Yum Yum	147	4000	1500	1,862	330	3%	32%	64%	1%
602	GA	Waynesboro	White Oak	76.5	516.7	516.7	2,995	1,790	1%	34%	65%	0%
603	GA	Butler	Butler GA	103	2395.1	2395.1	1,534	255	2%	73%	23%	2%
604	GA	Butler	White Pine	101.2	505.94	505.94	1,044	100	1%	51%	48%	1%
605	GA	Metter	Live Oak	51	417.84	417.84	910	235	4%	72%	23%	0%
606	GA	Hazelhurst	Hazelhurst II	52.5	947.15	490.42	2,114	105	9%	64%	27%	0%
607	GA	Bainbridge	Decatur Parkway	80	781.5	781.5	1,123	450	2%	27%	22%	49%
608	GA	Leslie-DeSoto	Americus	1000	9661.2	4437	5,210	510	1%	63%	36%	0%
616	FL	Fort White	Fort White	74.5	570.5	457.2	828	220	12%	71%	17%	0%
621	VA	Spring Grove	Loblolly	150	2181.9	1000	1,860	110	7%	62%	31%	0%
622	VA	Scottsville	Woodridge	138	2260.9	1000	1,094	170	9%	63%	28%	0%
625	NC	Middlesex	Phobos	80	754.52	734	356	57	14%	75%	10%	0%
628	MI	Deerfield	Carroll Road	200	1694.8	1694.8	343	190	12%	86%	0%	2%
633	VA	Emporia	Brunswick	150.2	2076.4	1387.3	1,091	240	4%	85%	11%	0%
634	NC	Elkin	Partin	50	429.4	257.64	945	155	30%	25%	15%	30%

Parcel #	State	City	Name	Output (MW)	Total Acres	Used Acres	Avg. Dist to home	Closest Home	Adjoining Use by Acre Res	Agri	Ag/R	Com
638	GA	Dry Branch	Twiggs	200	2132.7	2132.7	-	-	10%	55%	35%	0%
639	NC	Hope Mills	Innovative Solar 46	78.5	531.87	531.87	423	125	17%	83%	0%	0%
640	NC	Hope Mills	Innovative Solar 42	71	413.99	413.99	375	135	41%	59%	0%	0%
645	NC	Stanley	Hornet	75	1499.5	858.4	663	110	30%	40%	23%	6%
650	NC	Grifton	Grifton 2	56	681.59	297.6	363	235	1%	99%	0%	0%
651	NC	Grifton	Buckleberry	52.1	367.67	361.67	913	180	5%	54%	41%	0%
657	KY	Greensburg	Horseshoe Bend	60	585.65	395	1,394	63	3%	36%	61%	0%
658	KY	Campbellsville	Flat Run	55	429.76	429.76	408	115	13%	52%	35%	0%
666	FL	Archer	Archer	74.9	636.94	636.94	638	200	43%	57%	0%	0%
667	FL	New Smyrna Bea	Pioneer Trail	74.5	1202.8	900	1,162	225	14%	61%	21%	4%
668	FL	Lake City	Sunshine Gateway	74.5	904.29	472	1,233	890	11%	80%	8%	0%
669	FL	Florahome	Coral Farms	74.5	666.54	580	1,614	765	19%	75%	7%	0%
672	VA	Appomattox	Spout Spring	60	881.12	673.37	836	335	16%	30%	46%	8%
676	TX	Stamford	Alamo 7	106.4	1663.1	1050	-	-	6%	83%	0%	11%
677	TX	Fort Stockton	RE Roserock	160	1738.2	1500	-	-	0%	100%	0%	0%
678	TX	Lamesa	Lamesa	102	914.5	655	921	170	4%	41%	11%	44%
679	TX	Lamesa	Ivory	50	706	570	716	460	0%	87%	2%	12%
680	TX	Uvalde	Alamo 5	95	830.35	800	925	740	1%	93%	6%	0%
684	NC	Waco	Brookcliff	50	671.03	671.03	560	150	7%	21%	15%	57%
689	AZ	Arlington	Mesquite	320.8	3774.5	2617	1,670	525	8%	92%	0%	0%
692	AZ	Tucson	Avalon	51	479.21	352	-	-	0%	100%	0%	0%
				81								
			Average	111.80	1422.4	968.4	1031	263	10%	62%	22%	6%
			Median	80.00	914.5	646.0	836	188	7%	64%	17%	0%
			High	1000.00	9661.2	4813.5	5210	1790	58%	100%	100%	70%
			Low	50.00	347.1	185.1	343	57	0%	0%	0%	0%

VIII. Distance Between Homes and Panels

I have measured distances at matched pairs as close as 105 feet between panel and home to show no impact on value. This measurement goes from the closest point on the home to the closest solar panel. This is a strong indication that at this distance there is no impact on adjoining homes.

However, in tracking other approved solar farms, I have found that it is common for there to be homes within 100 to 150 feet of solar panels where visual barriers are possible.

As can be seen in the paired sales in this report, visual barriers are often harder to establish in the Southwest and instead larger setbacks are typically used, though some have included solid walls as visual barriers. The paired sales in the Southwest include sales data with homes as close as 970 feet to the nearest panel where there is no visual barrier with no impact on property value.

There are numerous examples of homes at Alamo 2 solar where the only visual buffer are slats in the fences that do not appear to obscure the solar farm very much and the adjoining homes here are as close as 150 feet with this minimal buffer.

Given this data the proposed 2,120 feet to the closest home at the subject property is substantially further than the data indicates is needed to protect property value.

IX. Topography

As shown on the summary charts for the solar farms, I have been identifying the topographic shifts across the solar farms considered. Differences in topography can impact visibility of the panels, though typically this results in distant views of panels as opposed to up close views. The topography noted for solar farms showing no impact on adjoining home values range from as much as 160-foot shifts across the project. Given that appearance is the only factor of concern and that distance plus landscape buffering typically addresses up close views, this leaves a number of potentially distant views of panels. I specifically note that in Crittenden in KY there are distant views of panels from the adjoining homes that showed no impact on value.

General rolling terrain with some distant solar panel views are showing no impact on adjoining property value.

The subject property only has 100 feet of difference across the solar farm which is less than what is shown in the paired sales. This coupled with the exceptionally long distance between nearby homes and panels supports a finding of no impact related to the topography.

X. Scope of Research

I have researched over 1,000 solar farms and sites on which solar farms are existing and proposed in New Mexico, Texas, Arizona, Indiana, Ohio, Virginia, Illinois, Tennessee, North Carolina, Kentucky as well as other states to determine what uses are typically found in proximity with a solar farm. The data I have collected and provide in this report strongly supports the assertion that solar farms are having no negative consequences on adjoining agricultural and residential values.

Beyond these references, I have quantified the adjoining uses for a number of solar farm comparables to derive a breakdown of the adjoining uses for each solar farm. The chart below shows the breakdown of adjoining or abutting uses by total acreage.

Percentage By Adjoining Acreage	Res	Ag	Res/AG	Comm	Ind	Avg Home	Closest Home	All Res Uses	All Comm Uses
Average	19%	53%	20%	2%	6%	887	344	91%	8%
Median	11%	56%	11%	0%	0%	708	218	100%	0%
High	100%	100%	100%	93%	98%	5,210	4,670	100%	98%
Low	0%	0%	0%	0%	0%	90	25	0%	0%

Res = Residential, Ag = Agriculture, Com = Commercial

Total Solar Farms Considered: 705

I have also included a breakdown of each solar farm by number of adjoining parcels to the solar farm rather than based on adjoining acreage. Using both factors provide a more complete picture of the neighboring properties.

Percentage By Number of Parcels Adjoining	Res	Ag	Res/AG	Comm	Ind	Avg Home	Closest Home	All Res Uses	All Comm Uses
Average	61%	24%	9%	2%	4%	887	344	93%	6%
Median	65%	19%	5%	0%	0%	708	218	100%	0%
High	100%	100%	100%	60%	78%	5,210	4,670	105%	78%
Low	0%	0%	0%	0%	0%	90	25	0%	0%

Res = Residential, Ag = Agriculture, Com = Commercial

Total Solar Farms Considered: 705

Both of the above charts show a marked residential and agricultural adjoining use for most solar farms. Every single solar farm considered included an adjoining residential or residential/agricultural use.

XI. Specific Factors Related To Impacts on Value

I have completed a number of Impact Studies related to a variety of uses and I have found that the most common areas for impact on adjoining values typically follow a hierarchy with descending levels of potential impact. I will discuss each of these categories and how they relate to a solar farm.

1. Hazardous material
2. Odor
3. Noise
4. Traffic
5. Stigma
6. Appearance

1. Hazardous material

A solar farm presents no potential hazardous waste byproduct as part of normal operation. Any fertilizer, weed control, vehicular traffic, or construction will be significantly less than typically applied in a residential development and even most agricultural uses.

The various solar farms that I have inspected and identified in the addenda have no known environmental impacts associated with the development and operation.

2. Odor

The various solar farms that I have inspected produced no odor.

3. Noise

Whether discussing passive fixed solar panels, or single-axis trackers, there is no negative impact associated with noise from a solar farm. The transformer reportedly has a hum similar to an HVAC that can only be heard in close proximity to this transformer and the buffers on the property are sufficient to make emitted sounds inaudible from the adjoining properties. No sound is emitted from the facility at night.

The various solar farms that I have inspected were inaudible from the roadways.

4. Traffic

The solar farm will have no onsite employee's or staff. The site requires only minimal maintenance. Relative to other potential uses of the site (such as a residential subdivision), the additional traffic generated by a solar farm use on this site is insignificant.

5. Stigma

There is no stigma associated with solar farms and solar farms and people generally respond favorably towards such a use. While an individual may express concerns about proximity to a solar farm, there is no specific stigma associated with a solar farm. Stigma generally refers to things such as adult establishments, prisons, rehabilitation facilities, and so forth.

Solar panels have no associated stigma and in smaller collections are found in yards and roofs in many residential communities. Solar farms are adjoining elementary, middle and high schools as well as churches and subdivisions. I note that one of the solar farms in this report not only adjoins a church, but is actually located on land owned by the church. Solar panels on a roof are often cited as an enhancement to the property in marketing brochures.

I see no basis for an impact from stigma due to a solar farm.

6. Appearance

I note that larger solar farms using fixed or tracking panels are a passive use of the land that is in keeping with a rural/residential area. As shown below, solar farms are comparable to larger greenhouses. This is not surprising given that a greenhouse is essentially another method for collecting passive solar energy. The greenhouse use is well received in residential/rural areas and has a similar visual impact as a solar farm.




The solar panels are all less than 15 feet high, which means that the visual impact of the solar panels will be similar in height to a typical greenhouse and lower than a single-story residential dwelling. Were the subject property developed with single family housing, that development would have a much greater visual impact on the surrounding area given that a two-story home with attic could be three to four times as high as these proposed panels.

Whenever you consider the impact of a proposed project on viewshed or what the adjoining owners may see from their property it is important to distinguish whether or not they have a protected viewshed or not. Enhancements for scenic vistas are often measured when considering properties that adjoin preserved open space and parks. However, adjoining land with a preferred view today conveys no guarantee that the property will continue in the current use. Any consideration of the impact of the appearance requires a consideration of the wide variety of other uses a property already has the right to be put to, which for solar farms often includes subdivision development, agricultural business buildings such as poultry, or large greenhouses and the like.

Dr. Randall Bell, MAI, PhD, and author of the book **Real Estate Damages**, Third Edition, on Page 146 "Views of bodies of water, city lights, natural settings, parks, golf courses, and other amenities are considered desirable features, particularly for residential properties." Dr. Bell continues on Page 147 that "View amenities may or may not be protected by law or regulation. It is sometimes argued that views have value only if they are protected by a view easement, a zoning ordinance, or covenants, conditions, and restrictions (CC&Rs), although such protections are relatively uncommon as a practical matter. The market often assigns significant value to desirable views irrespective of whether or not such views are protected by law."

Dr. Bell concludes that a view enhances adjacent property, even if the adjacent property has no legal right to that view. He then discusses a "borrowed" view where a home may enjoy a good view of vacant land or property beyond with a reasonable expectation that the view might be partly or completely obstructed upon development of the adjoining land. He follows that with "This same concept applies to potentially undesirable views of a new development when the development conforms to applicable zoning and other regulations. Arguing value diminution in such cases is difficult, since the possible development of the offending property should have been known." In other words, if there is an allowable development on the site then arguing value diminution with such a development would be difficult. This further extends to developing the site with alternative uses that are less impactful on the view than currently allowed uses.

This gets back to the point that if a property has development rights and could currently be developed in such a way that removes the viewshed such as a residential subdivision, then a less intrusive use such as a solar farm that is easily screened by landscaping would not have a greater impact on the viewshed of any perceived value adjoining properties claim for viewshed. Essentially, if there are more impactful uses currently allowed, then how can you claim damages for a less impactful use.

In areas where landscape screening is not a viable option, slats in the fences can be used as well as further setbacks to address appearance concerns.

7. Conclusion

On the basis of the factors described above, it is my professional opinion that the proposed solar farm will not negatively impact adjoining property values. The only category of impact of note is appearance, which is addressed through the oversized setbacks from nearby housing. The matched pair data supports that conclusion.

XII. Conclusion on Solar Farm Impact on Property Value

The matched pair analysis shows no negative impact in home values due to abutting or adjoining a solar farm as well as no impact to abutting or adjacent vacant residential or agricultural land. The criteria that typically correlates with downward adjustments on property values such as noise, odor, and traffic all support a finding of no impact on property value.

Very similar solar farms in very similar areas have been found by hundreds of towns and counties not to have a substantial injury to abutting or adjoining properties, and many of those findings of no impact have been upheld by appellate courts. Similar solar farms have been approved adjoining agricultural uses, schools, churches, and residential developments.

I have found no difference in the mix of adjoining uses or proximity to adjoining homes based on the size of a solar farm and I have found no significant difference in the matched pair data adjoining larger solar farms versus smaller solar farms. The data in the Southwest is consistent with the larger set of data that I have nationally, as is the more specific data located in and around New Mexico.

Based on the data and analysis in this report, it is my professional opinion that the solar farm proposed at the subject property will have no negative impact on the value of adjoining or abutting property. I note that some of the positive implications of a solar farm that have been expressed by people living next to solar farms include protection from future development of residential developments or other more intrusive uses, reduced dust, odor and chemicals from former farming operations, protection from light pollution at night, it's quiet, and there is no traffic.

XIII. Battery Energy Storage System (BESS)

I considered the following battery storage facilities in a variety of states for a comparison of similar battery energy storage systems (BESS) in proximity to residential uses. I have also searched these areas for recent sales to see if there is any impact on property values near these battery storage facilities, which will be addressed in the following section.

The primary use of this larger set is to show compatibility of BESS and residential uses as well as showing typical setbacks between these uses. These measured distances are from the closest point on the home to the closest piece of equipment. Where I have N/A, the facility does not have an aerial image that I can use to measure that distance. These distances were measured using GoogleEarth.

I note that the proposed distances at the subject property are very consistent with these and falls between the average and median distances for the closest homes and the average distance is much further away than these comparable projects.

Summary of Battery Data
NC

#	Name	City/State	Acres	Capacity	Distance from Closest Home	Average Distance Adjoining Home
1	Ozone Park	Queens, NY	0.35	3 MW	30	203
2	Pomona	Rockland, NY	28.5	N/A	270	1196
3	Asheville	Asheville, NC	12.36	9 MW	130	452
4	East Hampton	E. Hampton, NY	17.58	5 MW	470	733
5	Diablo	Concord, CA	11.45	200 MW	320	361
6	Prospect	W. Columbia, TX	2.3	10 MW	400	400
7	Brazoria	Brazoria, TX	17.58	9.95 MW	130	438
8	Gambit	Angleton, TX	6.24	100 MW	215	243
9	Churchtown	Pennsville, NJ	3.13	10 MW	N/A	N/A
10	West Chicago	Chicago, IL	5	19.8 MW	430	450
11	McHenry	McHenry, IL	2.75	19.8 MW	260	283
12	Plumstead	Hornerstown, NJ	14.39	19.8 MW	155	943
13	Vista	Vista, CA	0.88	40 MW	130	172
14	Chisholm	Ft Worth, TX	21.74	200 MW	840	875
15	Port Lavaca	Prt Lavaca, TX	1.44	9.9 MW	N/A	N/A
16	Magnolia	Houston, TX	0.87	9.95 MW	180	190
				Average	283	496
				Median	238	419
				High	840	1,196
				Low	30	172

Subject Property Name	Acres	Capacity	Distance from Closest Home	Average Distance Adjoining Home
Liberty	36.7	80 MW/320 MWh	240	796

A. BESS Paired Sales Analysis/Market Research

I considered the following battery storage facilities in a variety of states where I was able to identify adjoining residential home sales. These home sales were then compared to similar homes in the area that sold in the same time frame but were not in proximity to the BESS. This is called a paired sales analysis and I have used this to determine if there is any impact that could be attributed to the adjacency/proximity to the BESS.

1 - Ozone Park Batteries

This system is located on 99th Street in Jamaica, Queens, New York. The below image shows the battery pack parcel outlined in red with a bowling alley to the north, a school to the south and homes to the east and west as well as a church to the west. Based on aerial imagery, this site was installed in early to mid-2018.

The two closest structures are the school at 65 feet and a church at 30 feet from the batteries. The nearby homes are on the opposing blocks, but the proximity to the school does illustrate a high confidence in public safety related to the battery facility and acceptance within that community.

Surrounding Uses

#	Address	GIS Data Acres	Present Use	Adjoin Acres	Adjoin Parcels	Distance (ft) Home/Battery
1	98-18 Rockaway	0.76	Bowling	11.69%	6.67%	N/A
2		0.95	Office	14.62%	6.67%	N/A
3	10735 100th St	0.06	Residential	0.92%	6.67%	245
4	10737 100th St	0.06	Residential	0.92%	6.67%	260
5	10739 100th St	0.06	Residential	0.92%	6.67%	275
6	10741 100th St	0.06	Residential	0.92%	6.67%	290
7	10743 100th St	0.06	Residential	0.92%	6.67%	305
8	10915 98th St	3.74	School	57.54%	6.67%	65
9		0.27	School	4.15%	6.67%	N/A
10	10656 98th St	0.06	Residential	0.92%	6.67%	200
11	10654 98th St	0.06	Residential	0.92%	6.67%	195
12	10650 98th St	0.06	Residential	0.92%	6.67%	190
13	10646 98th St	0.06	Residential	0.92%	6.67%	190
14	10636 98th St	0.06	Residential	0.92%	6.67%	195
15	10645 (8th St	0.18	Church	2.77%	6.67%	30
	Total	**6.500**		**100.00%**	**100.00%**	203
					Min	30

The closest recent home sale is 10726 101st Street that sold on October 9, 2018, after the battery storage facility was installed. This home is 345 feet from the closest battery and has a very obstructed view of that area based on the shrubs around the battery storage site as well as a strip of landscape greenery between the two sites. The sales price was $600,000 for this 3 BR/1.5 BA home that was built in 1930 on a 0.06-acre site.

I compared this to a similar home built in 1930 in the same style and same size that sold at 10762 101st Street on October 9, 2018 for $590,000. This home is just down the street but further from the battery storage system and sold on the same day for $10,000 less. The proximity to the battery does not correlate to value impact in this instance as the home further away sold for less. This second home is across the street from the three-story John Adams High School which likely accounts for the lower price for this second property compared to the first which was adjacent to the same school, but not across from the building itself.

The matched pairs support a finding of no impact on value due to proximity to the battery system.

2 - Pomona Batteries

This battery storage system is located at 23 Diltz Road, Pomona, Rockland, New York. This location is more remote than the other system with greater distances separating homes from batteries, but all of the adjoining uses are residential or park. This battery site is located at the end of a road for estate-like homes on large acreage adjoining or in close proximity to Harriman State Park. There are some sales on Dritz Road adjoining the battery site and none of the broker statements identify that as a concern. But given the park, the Mahwah River exposure it is difficult to use these sales for matched pairs as there are too many unique factors and matched pairs require one unique factor.

Still, the site shows harmonious use in connection with residential uses. The closest identified home is 270 feet.

3 - Asheville Energy Storage System

This 9 MW battery storage system is located on a parcel with a substation built in 2020 (substation was bult much earlier). This facility has significant residential development around it but no recent sales to consider.

There is a nearby home sale that is located on Tax Parcel 8047 (just below the identifier for Parcel 9). This home is 550 feet from the nearest battery equipment and most of that distance is heavily wooded. This home has a street address of 95 Forest Lake Drive, Asheville, NC and it sold on April 26, 2022 for $510,000 for this 4 BR/3 BA ranch with 1,931 square feet including the daylight basement area. The home also has a 2 car garage. I did not attempt a paired sale as this home has no visibility of the BESS despite the proximity and arguably has a better view with less screening to the substation, which is also closer to the home.

Similarly, new homes are being built to the south on Rangley Drive with prices ranging from $431,000 to $566,000. These homes include those that back up to the Parcels 11 through 14 in the adjacent parcel map.

4 – East Hampton Energy Storage System

This 5 MW battery storage system is located on a parcel with a substation and a natural gas peaker plant. This makes it difficult to use for analysis given the multiple uses on this parcel, but I have included a visual of homes in the general area that have sold recently for reference. There is significant wooded acreage separating this BESS and nearby homes.

5 – Diablo Energy Storage System

This 200 MW battery storage system is located on a parcel with significant adjacency to industrial uses and residential uses. For these reasons it would be difficult to measure impacts due to the other adjoining industrial uses that might also have an impact. Given that most of the adjoining uses are industrial, I have not dug further on this one.

6 – Prospect Energy Storage System

This 10 MW battery storage system is located on a parcel adjoining a large substation in Brazoria, TX. The only adjoining home is 400 feet away. This home has not sold since the BESS was completed in 2019. Furthermore, this home has an unobstructed view of the substation which would make it a difficult home for impact analysis.

7 – Brazoria Energy Storage System

This 9.95 MW battery storage system is located on a parcel adjoining multiple homes within 150 feet of the battery equipment. There have been no recent sales since this was built in 2020.

8 - Gambit Energy Storage

This 102.4 MW battery storage system is located off W. Live Oak Street, Angleton, Texas. This is a new facility and placed online in June 2021. This system is a good location as there are no other externalities adjoining it to potentially impact the analysis. The substation associated with this is located to the east along N. Walker Street.

While I cannot do any analysis of impact from the most recent adjoining sales as they all occurred before this site was built, but the adjoining homes to the north are selling with new homes ranging from $400,000 to $600,000.

The most recent adjoining home sale to the west was 852 Marshall Road that sold on April 5, 2021 and presumably they were aware of the battery storage facility as it would have been under construction at the time of sale. This brick ranch with 3 BR, 1 BA with 1,220 s.f. of gross living area and built in 1980 on 0.40 acres sold for $165,000, or $135 per s.f.

I have compared that sale to 521 Catalpa Street that sold on September 11, 2020 for $155,000 for a 3 BR, 2 BA brick ranch with 1,220 s.f. built in 1973 with a single car garage. Adjusting this price upward by 9% for growth in the market for time, 3.5% for difference in age, downward by $6,000 for the additional bathroom, and $4,000 for the garage, the adjusted indicated value of this home is $164,375, which is right in line with 852 Marshall Road and supports a finding of no impact on property value.

I have also compared that sale to 521 W Mimosa Street that sold on February 26, 2021 for $150,000 for this brick ranch with 3 BR, 1.5 BA with 1,194 s.f. built in 1976. Adjusting this sale upward by 4% for growth in the market over time, upward 2% for difference in age, and downward by $5,000 for the additional half bathroom, I derive an adjusted indication of $154,000. This is 7%

less than the home price at 852 Marshall Road which suggests an enhancement due to proximity to the battery storage system.

I have also compared this sale to 1164 Thomas Drive that sold on May 20, 2020 for $187,000 for this brick ranch with 2-car garage, 3 BR, 2 BA with 1,259 s.f. and built in 1998. Adjusting this upward by 13% for growth over time, downward by 9% for difference in age of construction, downward by $8,000 for the garage, downward $6,000 for the additional bathroom, I derive an indicated value of $180,480. This is a 9% difference suggesting a negative impact on property value. However, this comparable required the largest amount of adjustments and is not considered as heavily as the other two comparables. This home is 18 years newer and with better bathroom situation as a 1-bathroom house is a significant issue for most buyers.

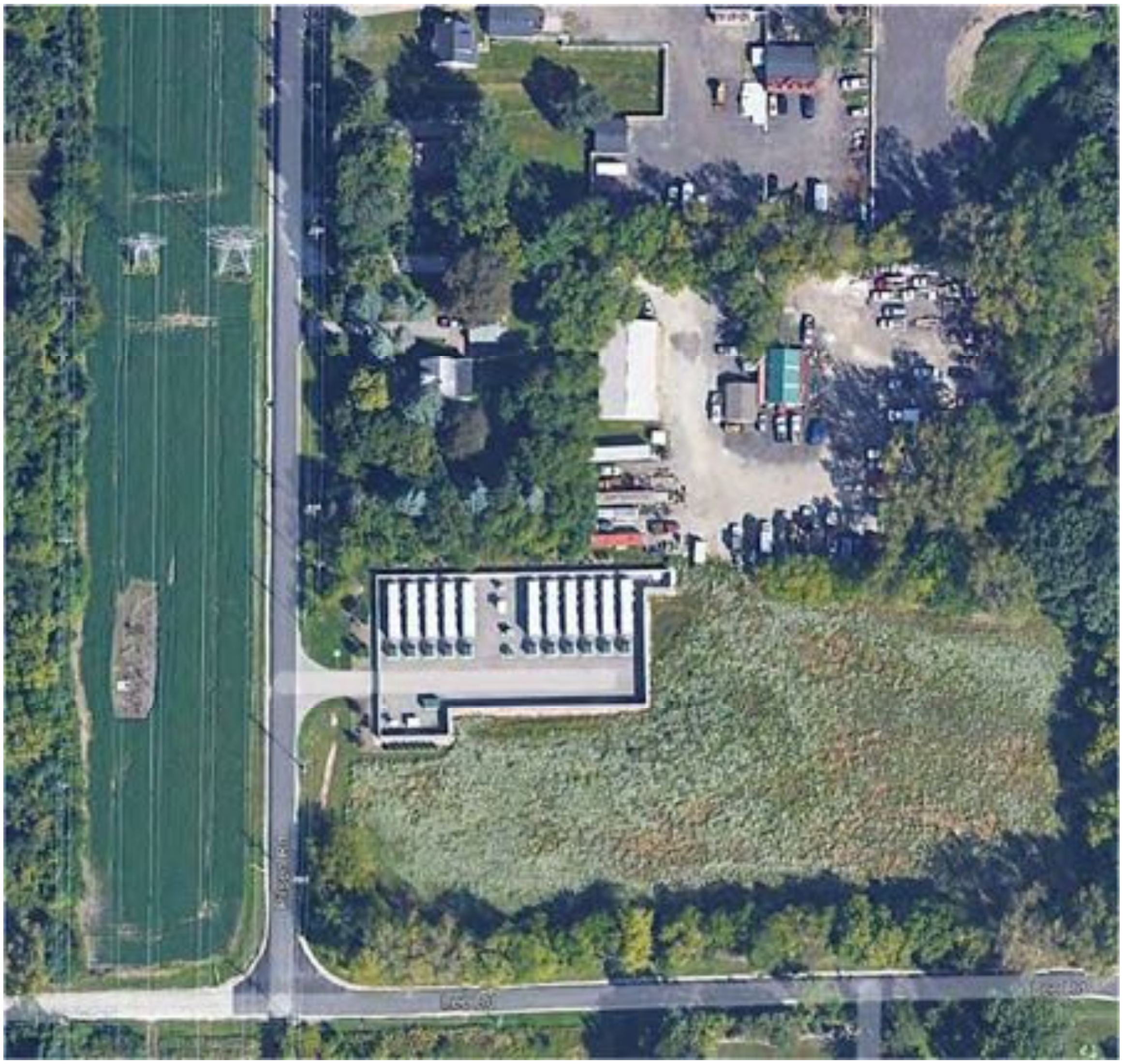
The second comparable considered required the least adjustment and suggests a positive impact on property value. The median indication is the first comparable which shows no impact on property value. Given this data set I conclude that the best indication from these matched pairs supports a finding of no impact on property value. The home at 852 Marshall is 180 feet from the project outline shown.

9 - Churchtown Battery Storage

This 10 MW battery storage system is located off N. Broadway, Pennsville, NJ. The aerial imagery does not show this system yet so I was not able to determine distances to adjoining homes or identify any adjoining homes. Given the large substation, adjoining baseball fields and religious facilities this would be a challenging site for an impact analysis in any case.

10 - West Chicago Battery Storage

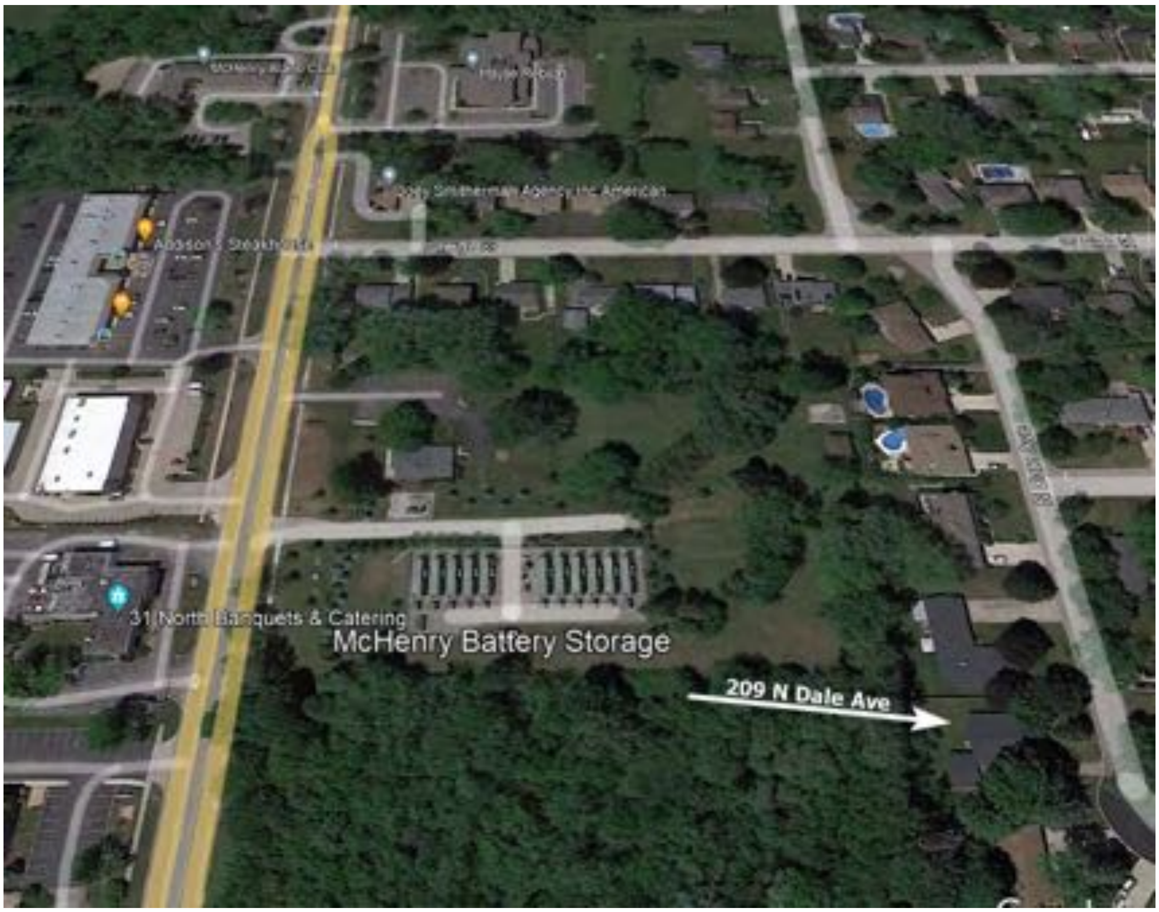
This 19.8 MW battery storage system is located off Pilsen Road, Chicago, Illinois. This facility has condominium and single family housing to the north and single family housing nearby to the south, but also adjoining an outdoor storage area and a large powerline easement. I was not able to do any analysis on this site as there have been no recent sales identified.



11 - McHenry Battery Storage

This 19.8 MW battery storage system is located off Illinois Highway 31, McHenry, Illinois that was built around 2016. This is facility fronts on the highway but has rear adjacency to a number of houses.

There were two recent home sales along W. High Street, but they effectively adjoin the small commercial use between the battery storage facility. That complication makes it difficult to determine if the commercial use was the impact or if the commercial use buffered any impact making any finding off of analysis suspect and uncertain.



I have however considered the recent sale of 209 N Dale Avenue that adjoins the battery storage site and is 290 feet from the nearest equipment.

That home sold on June 30, 2021 for $265,000 for a vinyl-siding ranch with 3 BR, 2.5 BA, built in 1960 with a gross living area of 1,437 square feet, or $184.41 per s.f. The property has 5 attached garage spaces. As identified in the listing the home was completely renovated with stainless steel appliances and granite countertops. This was listed by Lynda Steidinger with Berkshire Hathaway HomeServices Starck Real Estate and the buyers agent was Ivette Rodriguez Anderson with Keller Williams.

The home directly across the street, 208 N Dale Avenue, sold on June 16, 2021 for $275,000 for a cedar siding and stone ranch with 3 BR, 2.5 BA, built in 1961, with a gross living area of 1,446 s.f., or $190.18 per s.f. This home also has 1,101 square feet of finished basement space that is currently used as an office but could be an additional bedroom. This home also has been updated and includes stainless steel appliances and granite counter tops.

The size difference is nominal and the additional 3-car garage bays at the 209 N Dale is considered to be balanced by the finished basement space at 208 N Dale, though the finished office space is somewhat superior to garage space. But balancing those two factors out the difference in price per square foot is 3%. This is considered negligible and attributable to the slightly superior finished basement space and not any impact relative to the battery storage facility.

I also looked at 3802 Clover Avenue, which is two blocks to the north. This stone and siding ranch with 3 BR, 2 BA, built in 1956, with a gross living area of 1,200 s.f. sold on October 21, 2021 for $231,000 or $192.50 per s.f. The property has been updated with a new kitchen and a new bay window and includes a partially finished basement with an additional bathroom in it and the total basement area is an additional 1,200 s.f. This is the smallest home in the neighborhood that I found and it further illustrates that the price per square foot typically goes up as the size goes down. Adjusting this gross sale price upward by $36,498 for the smaller size based on 80% of the price per square foot for this purchase, I derive an adjusted sales price to compare to the subject property of $267,498. I consider the basement to balance out the extra garage space at the subject. This indicates a difference of 1% from the purchase price of the 209 N Dale Avenue, which is attributable to the 4 months difference in time. I consider this comparable to further support a finding of no impact on value.

While I haven't written up the other sales in the neighborhood there are numerous recent home sales ranging from $172,000 to $306,000, but most of these homes are also over 2,000 square feet in size. The subject property sold for more per square foot than most of these other sales partly due to the smaller overall size, partly due to the significant renovations, and partly due to the additional garage space. Still, this shows that the 209 N Dale Avenue sale is not being impacted by the battery storage facility and has in fact been updated above what is typical for the neighborhood, though given the similar updates at 208 N Dale Avenue, this may be the trend for the area.

The two sales compared to the 209 N Dale Avenue sale supports a finding of no impact on property value due to the battery storage facility.

12 - Plumsted Energy Storage

This 19.8 MW battery storage system is located on Monmouth Road, Cream Ridge, New Jersey. There is only one adjoining home as shown in the image to the south, but it is located just 148 feet from the nearest piece of equipment and 96 feet from the fence line. There were existing trees, but they were supplemented with a 12-foot wooden privacy fence with smaller evergreens between the fence and property line. The privacy fence at this location is oversized as the battery units include HVAC units on top of the battery pods that extend the height of the units greater than required at the subject property. The road frontage was not landscaped and chainlink fencing was used on the rest of the property.

The adjoining home at 797 Monmouth Road has not sold recently and no further analysis is possible at this site.

13 - Vista Energy Storage System

This 40 MW battery storage system is located off Olive Avenue, Vista, California. This facility has significant commercial development around it but also housing to the south as close as 115 feet from the closest equipment as shown in the aerial map below.

14 - Chisholm Grid Energy Storage

This 200 MW battery storage system is located at 9400 Asphalt Drive, Fort Worth, Texas. This is a new facility and in close proximity to those homes near the substation.

The property to the west of the BESS is an asphalt plant with a lot of vacant land separating the homes from the active plant. Still this complicates any analysis of this from an impact analysis standpoint. I therefore have not attempted to do so.

15 – Port Lavaca BESS

This 9.9 MW battery storage system is located in Port Lavaca, Texas. It was built in 2020 and is entirely surrounded by agricultural and utility uses. I have not attempted any impact analysis on this facility.

16 - BRP Magnolia BESS

This 9.95 MW battery storage system is located off Floyd Road, League City, near Houston, Texas. There have not been any adjoining home sales since it was built so no analysis is currently possible. The adjoining homes are between 180 and 200 feet from the BESS equipment.

Summary

I was able to complete paired sales analysis on three of these situations with data coming from Ozone Park in NY, Gambit in TX and McHenry in IL.

The paired sales analysis identifies no impact on adjoining properties based on actual home sales adjoining similar projects.

Most of the situations identified showed homes in much closer to a BESS than would be the case for the subject property where homes will be over 2,000 feet away.

The sales data supports a finding of no impact on property value for homes ranging from 180 to 345 feet from the nearest equipment.

XIV. Certification

I certify that, to the best of my knowledge and belief:

1. The statements of fact contained in this report are true and correct;

2. The reported analyses, opinions, and conclusions are limited only by the reported assumptions and limiting conditions, and are my personal, unbiased professional analyses, opinions, and conclusions;

3. I have no present or prospective interest in the property that is the subject of this report and no personal interest with respect to the parties involved;

4. I have no bias with respect to the property that is the subject of this report or to the parties involved with this assignment;

5. My engagement in this assignment was not contingent upon developing or reporting predetermined results;

6. My compensation for completing this assignment is not contingent upon the development or reporting of a predetermined value or direction in value that favors the cause of the client, the amount of the value opinion, the attainment of a stipulated result, or the occurrence of a subsequent event directly related to the intended use of the appraisal;

7. The reported analyses, opinions, and conclusions were developed, and this report has been prepared, in conformity with the requirements of the Code of Professional Ethics and Standards of Professional Appraisal Practice of the Appraisal Institute;

8. My analyses, opinions and conclusions were developed, and this report has been prepared, in conformity with the Uniform Standards of Professional Appraisal Practice.

9. The use of this report is subject to the requirements of the Appraisal Institute relating to review by its duly authorized representatives;

10. I have not made a personal inspection of the property that is the subject of this report, and;

11. No one provided significant real property appraisal assistance to the person signing this certification.

12. As of the date of this report I have completed the continuing education program for Designated Members of the Appraisal Institute;

13. I have not performed services, regarding the property that is the subject of this report within the three-year period immediately preceding acceptance of this assignment. I provided an earlier draft of this report on February 8, 2023.

Disclosure of the contents of this appraisal report is governed by the bylaws and regulations of the Appraisal Institute and the National Association of Realtors.

Neither all nor any part of the contents of this appraisal report shall be disseminated to the public through advertising media, public relations media, news media, or any other public means of communications without the prior written consent and approval of the undersigned.

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Kirkland Appraisals, LLC, Raleigh, N.C. 2003 – Present
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Hester & Company, Raleigh, N.C.
Commercial appraiser 1996 – 2003

PROFESSIONAL AFFILIATIONS

MAI (Member, Appraisal Institute) designation #11796 2001
NC State Certified General Appraiser # A4359 1999
VA State Certified General Appraiser # 4001017291
SC State Certified General Appraiser # 6209
FL State Certified General Appraiser # RZ3950
GA State Certified General Appraiser # 321885
MI State Certified General Appraiser # 1201076620
PA State Certified General Appraiser # GA004598
OH State Certified General Appraiser # 2021008689
IN State Certified General Appraiser # CG42100052

EDUCATION

Bachelor of Arts in English, University of North Carolina, Chapel Hill 1993

CONTINUING EDUCATION

Uniform Standards of Professional Appraisal Practice Update	2022
Sexual Harassment Prevention Training	2021
Appraisal of Land Subject to Ground Leases	2021
Michigan Appraisal Law	2020
Uniform Standards of Professional Appraisal Practice Update	2020
Uniform Appraisal Standards for Federal Land Acquisitions (Yellow Book)	2019
The Cost Approach	2019
Income Approach Case Studies for Commercial Appraisers	2018
Introduction to Expert Witness Testimony for Appraisers	2018
Appraising Small Apartment Properties	2018
Florida Appraisal Laws and Regulations	2018
Uniform Standards of Professional Appraisal Practice Update	2018
Appraisal of REO and Foreclosure Properties	2017
Appraisal of Self Storage Facilities	2017
Land and Site Valuation	2017
NCDOT Appraisal Principles and Procedures	2017
Uniform Standards of Professional Appraisal Practice Update	2016
Forecasting Revenue	2015
Wind Turbine Effect on Value	2015
Supervisor/Trainee Class	2015

Business Practices and Ethics	2014
Subdivision Valuation	2014
Uniform Standards of Professional Appraisal Practice Update	2014
Introduction to Vineyard and Winery Valuation	2013
Appraising Rural Residential Properties	2012
Uniform Standards of Professional Appraisal Practice Update	2012
Supervisors/Trainees	2011
Rates and Ratios: Making sense of GIMs, OARs, and DCFs	2011
Advanced Internet Search Strategies	2011
Analyzing Distressed Real Estate	2011
Uniform Standards of Professional Appraisal Practice Update	2011
Business Practices and Ethics	2011
Appraisal Curriculum Overview (2 Days – General)	2009
Appraisal Review - General	2009
Uniform Standards of Professional Appraisal Practice Update	2008
Subdivision Valuation: A Comprehensive Guide	2008
Office Building Valuation: A Contemporary Perspective	2008
Valuation of Detrimental Conditions in Real Estate	2007
The Appraisal of Small Subdivisions	2007
Uniform Standards of Professional Appraisal Practice Update	2006
Evaluating Commercial Construction	2005
Conservation Easements	2005
Uniform Standards of Professional Appraisal Practice Update	2004
Condemnation Appraising	2004
Land Valuation Adjustment Procedures	2004
Supporting Capitalization Rates	2004
Uniform Standards of Professional Appraisal Practice, C	2002
Wells and Septic Systems and Wastewater Irrigation Systems	2002
Appraisals 2002	2002
Analyzing Commercial Lease Clauses	2002
Conservation Easements	2000
Preparation for Litigation	2000
Appraisal of Nonconforming Uses	2000
Advanced Applications	2000
Highest and Best Use and Market Analysis	1999
Advanced Sales Comparison and Cost Approaches	1999
Advanced Income Capitalization	1998
Valuation of Detrimental Conditions in Real Estate	1999
Report Writing and Valuation Analysis	1999
Property Tax Values and Appeals	1997
Uniform Standards of Professional Appraisal Practice, A & B	1997
Basic Income Capitalization	1996

Exhibit 12

Do solar farms hurt property values? Most Americans don't have anything to worry about, study finds

march 2023

ELIZABETH WEISE | USA TODAY

A common argument against utility-scale solar energy farms is that they can severely decrease property values for surrounding homes. A study released by a federal laboratory this month found the effect was relatively small – and disappeared a mile from installations.

The study by Lawrence Berkeley National Laboratory looked at residential home prices in six states that together account for over 50% of the installed capacity of large-scale solar in the United States – California, Connecticut, Massachusetts, Minnesota, North Carolina and New Jersey.

The researchers found that homes within a quarter-mile of some utility-scale solar farms saw average property values decline 2.3% but there were no effects on homes more than a mile away.

"Previous analyses conducted by other researchers have found larger negative effects for homes located near confined animal feeding operations, landfills, fossil fuel plants, and highways," said Ben Hoen, a scientist in the Electricity Markets and Policy Department at the Lawrence Berkeley National Laboratory and one of the paper's authors.

How big was the study?

The researchers looked at over 1.8 million property transactions that occurred within six years before and after a utility-scale solar installation was constructed in the six states.

California, Massachusetts, Minnesota, North Carolina and New Jersey were chosen because they represented the top five states in terms of the number of large-scale solar installations built in the United States through 2019. Connecticut was added because it has a relatively high population density near solar projects.

The study is the largest so far looking at how solar installations affect property values.

Where do solar installations affect property values?

The researchers found the area where a solar installation is built has an enormous impact on whether it affects nearby home prices.

Homes in rural and agricultural areas saw declines in home prices, especially where solar farms were replacing agricultural land uses, as opposed to urban or suburban installations which saw no change in home prices.

The researchers noted the data was mostly from rural and agricultural areas that were relatively near towns or cities. said Hoen.

Because the study only looked at the price of homes within four miles of solar installations, truly rural and agricultural areas tended not to be included. "They can't be so rural that there aren't any homes near them," Hoen said.

The projects also tended to be medium-sized, most fewer than 35 acres. That was because large solar installations tend not to be built near areas where there are nearby homes that sold.

Did all states see the same property value effects?

The property value effects of large-scale solar projects were not consistent across the six states in the study.

"We see (the effects) very clearly in Minnesota, North Carolina and New Jersey for homes that are within a half mile of projects," Hoen said. "We don't see reductions in sale prices within a half mile of large-scale projects in California, Connecticut and Massachusetts."

On average, there were no statistically significant effects of building solar farms in these areas:

- Greenfields, meaning undeveloped land open for industrial use.
- Brownfields, meaning former industrial or commercial sites
- Mixed residential/commercial sites
- Urban areas

How much does a new solar installation affect a home's price?

On average, only homes within a mile of a solar farm saw any change in property values.

The amount property values were affected depended on how far from the solar farm the home was:

- Closer than a quarter mile, 2.3% decrease
- Quarter to a half a mile, 1.5% decrease
- Half a mile to one mile, 0.8% decrease

Where there ways to mitigate the effect on home prices?

The study didn't look specifically at how homeowners might be protected from possible loss of value in their homes but did note there are some tools that might be used by solar developers. That included compensation to nearby affected homeowners and landscape measures such as vegetative screening.

Hoen notes that while the study provided information about what was happening, it didn't answer the question of why it was happening. Why people who are buying and selling real estate in these communities discount some properties near solar projects is something they hope to study in the future.

Exhibit 13

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Shedding light on large-scale solar impacts: An analysis of property values and proximity to photovoltaics across six U.S. states

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ABSTRACT

We examine the impact of large-scale photovoltaic projects (LSPVPs) on residential home prices in six U.S. states that account for over 50% of the installed MW capacity of large-scale solar in the U.S. Our analysis of over 1,500 LSPVPs and over 1.8 million home transactions answers two questions: (1) what effect do LSPVPs have on home prices and (2) does the effect of LSPVP on home prices differ based on the prior land use on which LSPVPs are located, LSPVP size, or a home's urbanicity? We find that homes within 0.5 mi of a LSPVP experience an average home price reduction of 1.5% compared to homes 2–4 mi away; statistically significant effects are not measurable over 1 mi from a LSPVP. These effects are only measurable in certain states, for LSPVPs constructed on agricultural land, for larger LSPVPs, and for rural homes. Our results have two implications for policymakers: (1) measures that ameliorate possible negative impacts of LSPVP development, including compensation for neighbors, vegetative shading, and land use co-location are relevant especially to rural, large, or agricultural LSPVPs, and (2) place- and project-specific assessments of LSPVP development and policy practices are needed to understand the heterogeneous impacts of LSPVPs.

1. Introduction

Large-scale photovoltaic projects (LSPVP), defined here as ground-mounted photovoltaic generation facilities with at least 1 MW of DC generation capacity, are an increasingly prevalent source of renewable energy. LSPVPs accounted for over 60% of all new solar capacity in the United States in 2021, and, as the largest resource by capacity in interconnection queues, are projected to continue growing (Bolinger et al., 2021). However, the local economic impacts of LSPVPs are poorly understood (Mai et al., 2014), despite surveys showing that local public support for large-scale solar is strongly related to perceived economic impacts, including the impact on property values (Carlisle et al., 2014). Concerns surrounding the property value impacts of solar power are reflected in solar industry and environmental advocacy communication that challenge the conception that solar power reduces property values (Center for Energy Education, n.d.; Solar Energy Industries Association, 2019), and in attempts by neighbors of solar plants to claim solar panels as a private nuisance (Westgate, 2017).

The purpose of this paper is to provide some of the first comprehensive evidence on the impact of LSPVPs on residential home values. Specifically, we seek to answer two related research questions: (1) what effect, if any, do LSPVPs have on residential home prices and (2) does the effect of LSPVPs on home prices differ based on the prior land use on which a LSPVP is located, the size of the LSPVP, or the urbanicity of a home's location? To address these questions we use data from CoreLogic on over 1.8 million residential property transactions that occurred within six years before and after a LSPVP was constructed in the five U.S. states with the highest concentration of LSPVPs as measured by number of installations: California (CA), Massachusetts (MA), Minnesota (MN), North Carolina (NC), and New Jersey (NJ), as well as in Connecticut (CT), chosen for its relatively high population density (i.e., urbanicity) near LSPVPs. We then combine the transaction data with other geospatial datasets including an original dataset of LSPVP footprints developed by the project team for this research, a suite of environmental amenities and dis-amenities, urban, rural, and suburban classifications, and historic land cover data. We identify the arguably causal impact of LSPVPs on residential property values using a difference-in-differences identification strategy that compares the sale price of residential homes located in close proximity to a LSPVP (e.g. 0–0.5 miles away) both before and after a LSPVP is constructed to the sale price of homes located farther away from a LSPVP (e.g. 2–4 miles away).

Our paper makes several important contributions. First, we examine the impacts of LSPVPs in a large set of U.S. states that account for the

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Abbreviations

A/D	amenities and dis-amenities
API	Application Programming Interface
CA	California
CT	Connecticut
DC	direct current
dB	decibel
DiD	difference-in-difference
EIA	Energy Information Administration
FE	fixed effects
GHG	greenhouse gas
LSPVP	large-scale photovoltaic project
MA	Massachusetts
MN	Minnesota
MW	megawatt
NJ	New Jersey
NLCD	National Land Cover Database
NY	New York
NC	North Carolina
PV	photovoltaic
RI	Rhode Island
RPS	Renewable Portfolio Standard
SB	Senate Bill
U.K.	United Kingdom
U.S.	United States
USDA	United States Department of Agriculture

majority of U.S. LSPVP capacity, most of which, to our knowledge, have not previously been studied with respect to the impact of LSPVPs on property values. Existing research on the property value impacts of LSPVPs provides mixed results from a limited set of geographies. Where researchers do find an adverse impact of LSPVPs on property values, as in studies from the Netherlands and from the U.S. states of RI, MA, and NC, they theorize a change in property values due to visual intrusion from panels (Abashidze, 2019; Dröes and Koster, 2021; Gaur and Lang, 2020) and land use change (Gaur and Lang, 2020). Conversely, one study based in the U.K. finds no statistically significant effect of LSPVPs on property values (Jarvis, 2021). Expanding the geographic scope of the literature, then, facilitates both generalization (Brinkley and Leach, 2019) and more location-specific policy insights.

Second, we investigate whether the effect of LSPVPs on home prices is heterogenous with respect to LSPVP area, prior LSPVP land use, and home urbanicity. One of the major concerns surrounding LSPVPs, as well as one of the major opportunities to explore the co-benefits of LSPVP development, are its land use requirements (Hernandez et al., 2014a; Hernandez et al., 2014b; Katkar et al., 2021). In particular, more adverse home price impacts might be found where LSPVPs displace green space (consistent with results that show higher property values near green space (Crompton, 2001)) or where LSPVPs are larger in area, and thus more visually intrusive. While some previous studies (Gaur and Lang, 2020) find that greenfield solar development is primarily responsible for their observed decrease in home prices when compared to brownfield development, our constructed dataset of LSPVP footprints allows us to more precisely identify the prior land use of a LSPVP (for instance, breaking up the "greenfield" category into agricultural and non-agricultural land uses). Our dataset of LSPVP footprints additionally allows us to accurately characterize the area of each LSPVP.

In section 2, we introduce the policy context for LSPVP development in the study area and review the existing literature on property value impacts of LSPVPs. In section 3, we detail the data used in this study, the geospatial methods used to combine datasets, and the difference-in-differences approach to assessing property value impacts of LSPVPs. In section 4, we present our base model, event study, and heterogeneity analysis results. In section 5, we summarize and discuss our findings. In section 6, we note the limitations of our study and describe avenues for future work. Finally, in section 7, we review the key conclusions and policy implications of our study.

2. Background and relevant literature

2.1. Policy context

The study area is defined as the six states of CA, CT, MA, MN, NC, and NJ. The states in the study area were chosen based on number of installations: CA, NC, MA, MN, and NJ represent the top five states in terms of number of >1 MW DC solar installations through 2019. Together, these states contain over 2,000 solar projects, or approximately 53% of the total MW DC capacity in the United States through 2019. We additionally include CT because of its relatively high population density near solar projects (U.S. Energy Information Administration, 2021a).

All six states face increasing demands for large-scale solar along with intensifying land use and permitting constraints on solar development. Both CA and CT have ambitious Renewable Portfolio Standards (RPSs), aiming for 100% of electricity retail sales to be supplied by renewable sources by 2045 and 2040, respectively (Schwartz and Brueske, 2020; U.S. Energy Information Administration, 2021a). In CA, this necessitates, by some estimates, a tripling of California's renewable energy production; of those possible renewable resources, solar PV is both the least expensive and has the largest technical potential in the state (Schwartz and Brueske, 2020). Though MA, MN, and NJ have less ambitious renewable energy development goals, state reports still estimate that building solar PV is a key strategy to meeting both MA and MN's GHG reduction and renewable electricity sourcing targets (Jones et al., 2020; Putnam and Perez, 2018), and NJ introduced legislation in 2021 that aims to double existing solar installations through incentives (NJ Department of Environmental Protection, 2021). NC's solar future is less definite: although the state has, historically, been a leader in solar installations, the dominant electric utility in the state, Duke Energy, has proposed an integrated resource plan that largely privileges fossil generation over renewables. This plan is currently under review by the NC Utility Commission, with challenges from multiple environmental groups (Southern Environmental Law Center, 2021).

State reports identify persistent LSPVP land use and permitting challenges. In CA, for instance, San Bernardino county voted to ban utility-scale solar farms on over a million acres of private land (Schwartz and Brueske, 2020), citing concerns about the industrializing impact of solar projects on rural or desert landscapes (Roth, 2019). Tradeoffs between land use and LSPVP development are also observed at the state level in CT, MN, and NJ. In CT, Public Act 17–218, enacted in 2017, limits PV development on forest and prime farmland[1]; this has resulted in a reduced number of approved commercial PV projects per year (CT Council on Environmental Quality, 2020). Before the passage of this act, in 2016, the CT Council on Environmental Quality reported that solar PV was the single largest type of development displacing agricultural and forest land (CT Council on Environmental Quality, 2017). MN, too, prohibits solar development on prime farmland: the state's Prime

[1] Both CT Public Act 17–218 and the MA Prime Farmland Rule cite 7 CFR 657 for the definition of "prime farmland"; 7 CFR 657 is a periodically updated set of federal regulations, administered by the Department of Agriculture, that defines prime and important farmlands (Legal Information Institute, n.d.).

Farmland Rule includes solar development as one of the prohibited industrial uses of select agricultural land (Bergan, 2021). The MN Prime Farmland Rule is currently being contested: legislation that allows more PV development on farmland is now under consideration in the MN legislature (Bergan, 2021), and the MN Department of Commerce has, in the past, issued guidance for developers on how to make their case for an exception to the rule (Birkholz et al., 2020). In NJ and NC, too, concerns about farmland preservation and LSPVPs have appeared in discussions among agricultural stakeholders, although neither state has adopted prime farmland legislation like CT or MN (American Farmland Trust, 2021; Cleveland and Sarkisian, 2019). In MA, state reports refer to siting difficulties due to high population densities, expensive land for development that is disconnected from transmission, and opposition to disturbance of natural land (Jones et al., 2020).

In summary, while LSPVP installations are prevalent in the six states analyzed in this, these states also represent regions where an increasing need for LSPVP is met with restrictions, opposition, and land-use tradeoffs. These restrictions are often specific to farmland, although concerns do extend to other landscapes (like high density areas, deserts, and forests). Investigating property value impacts of LSPVPs, both overall and by prior land use and installation size, can potentially provide policymakers, practitioners, and developers with valuable information on how LSPVPs affect residents' willingness to pay for properties located near LSPVPs. To the extent that these concerns represent possible burdens of LSPVP development, investigating property value impacts of LSPVPs also helps us understand how these burdens are distributed. These insights, in turn, can guide policy or best practices that seek to mitigate adverse impacts of LSPVP development to enable build-out that meets climate and clean energy goals.

2.2. Relevant literature

The property value impacts of LSPVPs have received only recent, limited attention (Abashidze, 2019; Al-Hamoodah et al., 2018; Dröes and Koster, 2021; Gaur and Lang, 2020; Jarvis, 2021). Studies on LSPVPs and property values employing difference-in-differences (DiD) analyses find mixed results. Studies based in the U.S., specifically, MA and RI (Gaur and Lang, 2020) and NC (Abashidze, 2019), and the Netherlands (Dröes and Koster, 2021), find a statistically significant negative effect for homes near solar projects compared to homes further away. One study, based in the U.K., finds no statistically significant effect of LSPVP proximity on home property values (Jarvis, 2021). Although none of the existing studies find evidence of an increase in sales prices for homes near solar projects, Abashidze (2019) finds an increase in agricultural land value for land in close proximity to transmission lines after a solar farm is built in the area. To our knowledge, only Gaur and Lang (2020) investigate the impact of prior land use using a DiD framework, finding that greenfield solar construction is associated with a statistically significant reduction in sale prices in both rural and non-rural areas, with greater reductions observed in rural areas. One study using a contingent valuation survey finds that respondent willingness to pay for large-scale solar developments is a function of prior land use, where brownfield solar developments are more desirable than greenfield developments (Lang et al., 2021). Both Jarvis (2021) and Abashidze (2019) find no evidence of heterogeneity in home price impacts by income or other socio-economic indicators.

The mixed results to date in the LSPVP and property value literature motivates studies that look at previously understudied geographies to develop a more comprehensive view of the possible property value impacts of LSPVPs. The existing literature also orients us to relevant heterogeneity analyses, including heterogeneity by prior land use. We extend this literature by looking at a more specific set of prior land uses beyond greenfield and brownfield, as well as by looking at heterogeneity of effects by LSPVP size and urbanicity.

3. Methods

3.1. Data

This project utilized five major sources of data, shown on the left-most side of Fig. 1. First, to characterize and locate LSPVPs, we utilized the U.S. Energy Information Administration's Form 860 (U.S. Energy Information Administration, 2021b), which provides latitude-longitude data on solar plants, their installed capacities (in megawatts, MW), and their operation start date. We kept only solar plants within the study area with an installed capacity over 1 MW and eliminated rooftop installations, leaving us with 1,630 solar plants. Second, to understand the impact of prior LSPVP land use on property values, we used land use data from the United States Geological Survey (USGS)'s Multi-Resolution Land Characteristics (MRLC) Consortium's National Land Cover Database (NLCD) from 2006 (Multi-Resolution Land Characteristics Consortium, 2006). Third, for information about home sales, we used transaction data from CoreLogic (CoreLogic, n.d.), which provided information on location, property characteristics and transaction characteristics. We filtered this dataset for only relevant, complete records; the criteria used to screen data are outlined in Table A.1. Fourth, to identify amenities or disamenities (herein referred to as A/D), or landscape characteristics that could positively or negatively impact the price of a home, we used the data sources summarized in Table A.2. Finally, to understand the impact of urbanicity on property value impacts, we used the U.S. Census Bureau's (U.S. Census Bureau, n.d.) urban-urban cluster-rural classification (a metric based on population density, where urban areas are the most dense, followed by urban clusters, then rural areas). These data sources were validated and combined to produce a final analytic dataset. Fig. 1 graphically depicts the data preparation steps, which we describe below.

Step 1: To obtain a polygon representation of each LSPVP from the EIA point data, we first verified installation locations using satellite imagery from Esri and DigitalGlobe and revised project centroid coordinates where necessary. We manually drew polygons around the boundaries of each LSPVP based on satellite imagery; for projects that consisted of multiple, non-contiguous groups of panels, we drew a multipart polygon around the boundaries of each group of panels. We calculated a construction start year for each LSPVP, assuming construction begins one year before the EIA-provided operation start date. Fig. A.1 shows an example of two LSPVPs and their corresponding polygons; Fig. 2 shows the location of LSPVP sites as well as the density of transacted homes for the six states in the study area.

Additionally, in this step we determined the predominant prior land use type of each LSPVP. We first determined the distribution of prior land cover types by area for each LSPVP; each LSPVP polygon is composed of some proportion of the NLCD land cover classes shown in the right-most column of Table 1 (15 of the 16 possible NLCD classes showed up in our sample). Each LSPVP's distribution of NLCD classes was grouped and summed as per the left-most column of Table 1, and each LSPVP was assigned the predominant prior land use type that constituted 50% or more of its land cover. If no single predominant prior land use type accounted for 50% or more of an LSPVP's prior land cover by area, that LSPVP was assigned a predominant prior land use type of "mixed".[2] Fig. 3 shows (a) the proportion of displaced LSPVP area and

[2] For instance, a solar installation on land that was, in 2006, 15% barren land, 25% cultivated crops, 25% herbaceous, and 35% hay/pasture, would be generalized as 60% agriculture and 40% greenfield, and would be given the predominant prior land use type of "agriculture". A solar installation on land that was, in 2006, 15% barren land, 25% developed, high intensity, 25% herbaceous, and 35% hay/pasture, would be generalized as 35% agriculture, 40% greenfield, and 25% brownfield, a would be assigned the predominant prior land use type of "mixed", because no single category amounted to greater than 50%.

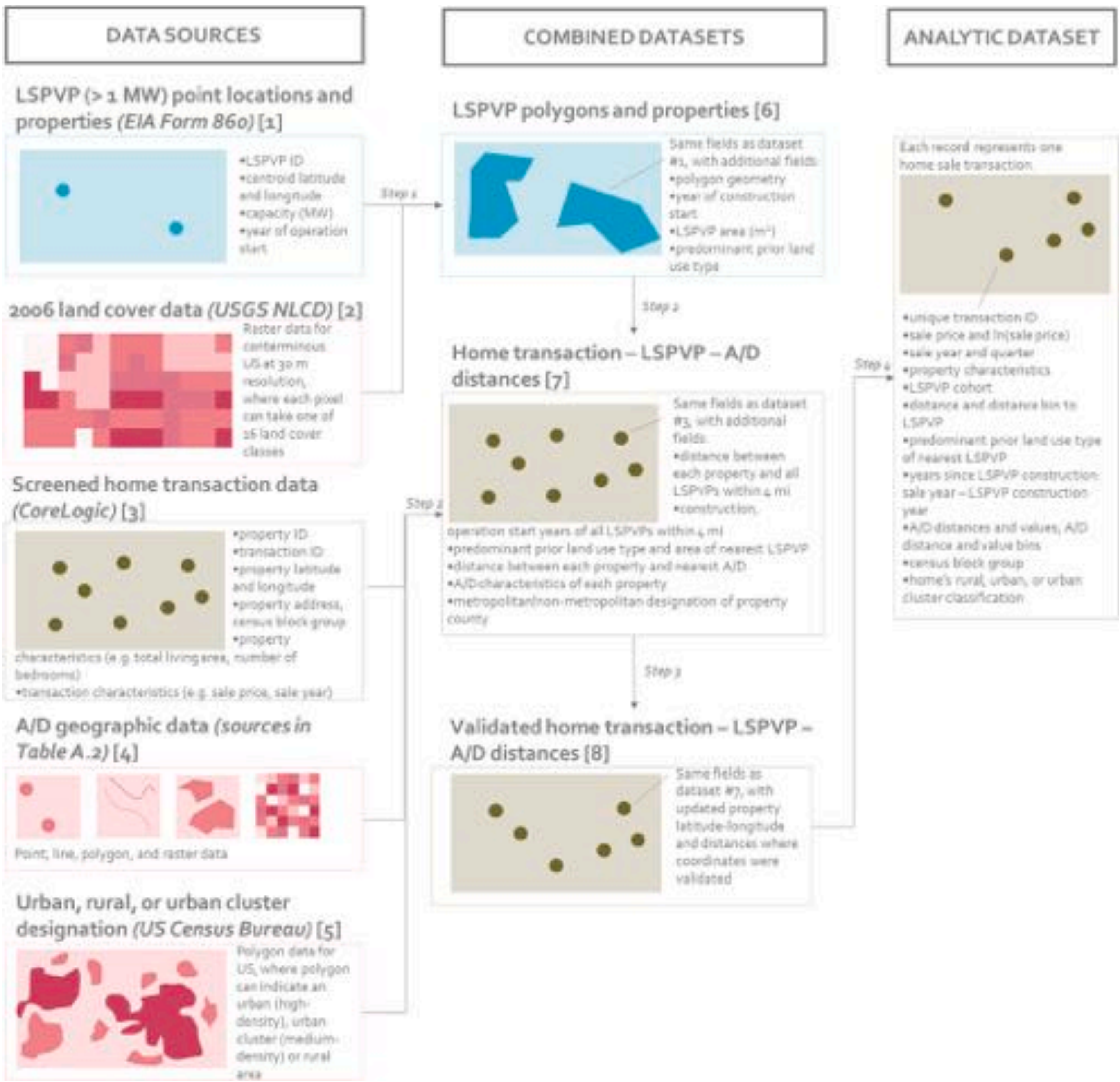

Fig. 1. Data sources and data preparation steps.

Table 1
Grouping of NLCD classes into predominant land use types; LSPVPs are assigned a predominant prior land use of "mixed" if their area does not contain 50% or more of the NLCD classes within a single predominant prior land use type.

Predominant prior land use type	NLCD classes
Agriculture	Cultivated Crops; Hay/Pasture
Brownfield	Developed, High Intensity; Developed, Low Intensity; Developed, Medium Intensity
Greenfield	Barren land; Deciduous forest; Developed, Open Space; Emergent Herbaceous Wetlands; Evergreen Forest; Herbaceous; Mixed Forest; Open Water; Shrub/Scrub; Woody Wetlands

Table 2
Transaction count by state in final analytic dataset.

State	Number of transactions
CA	933,037
CT	34,313
MA	291,325
MN	75,394
NC	204,134
NJ	297,756
6 state total	1,835,961

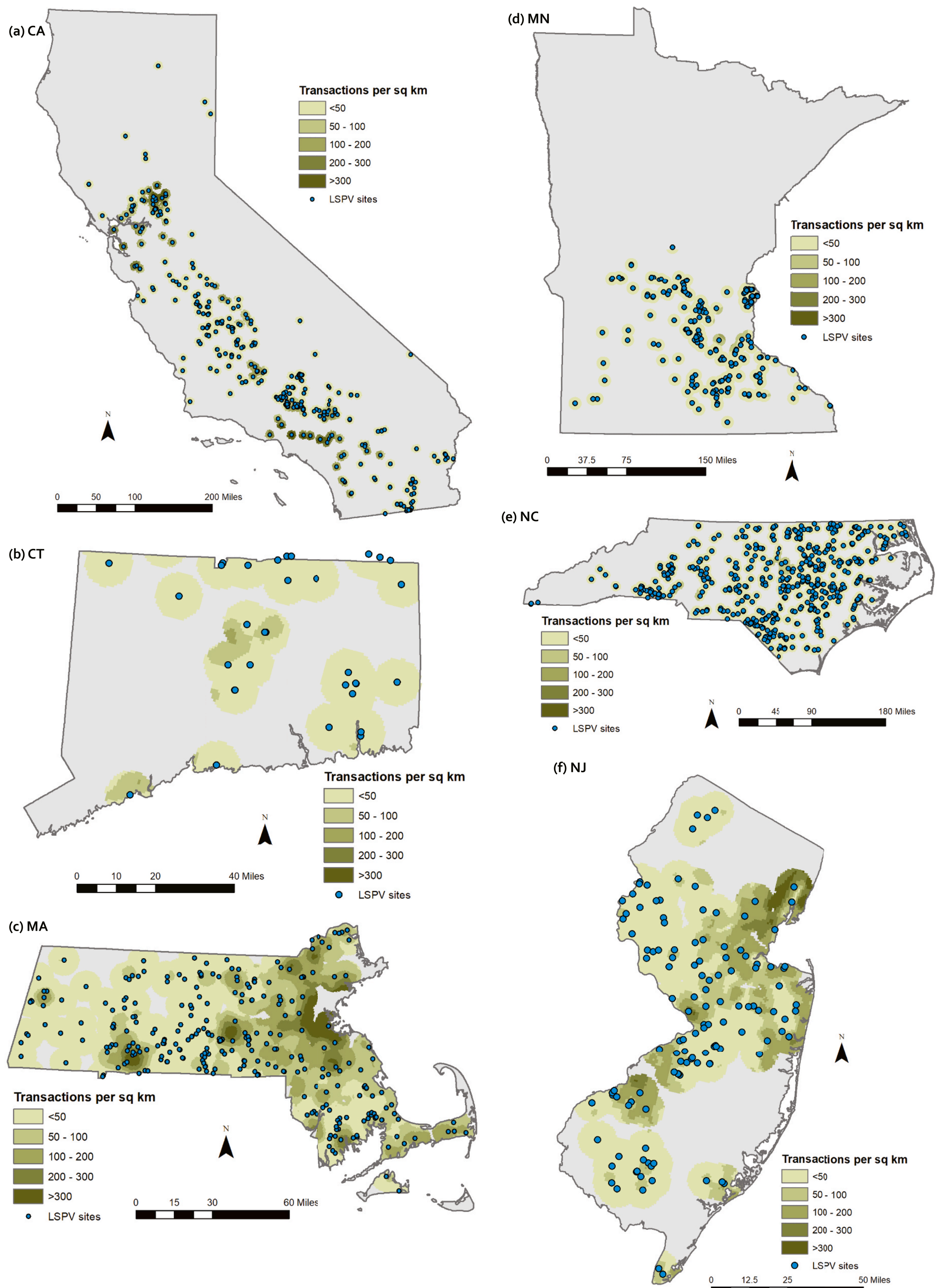

Fig. 2. Heat map of transacted home density within 5 miles of LSPVP sites in individual states.

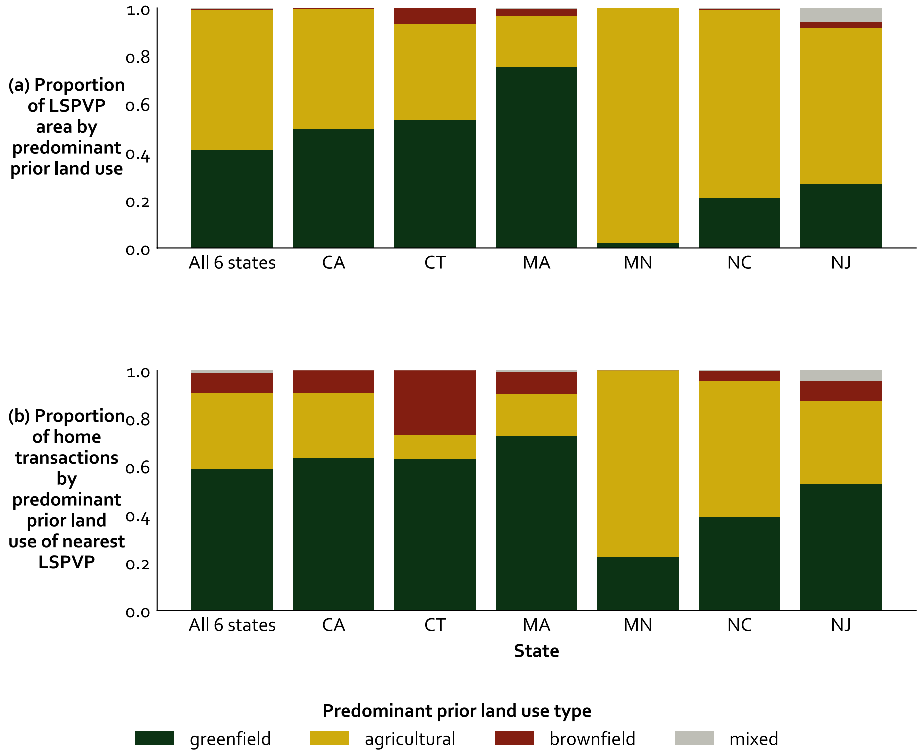

Fig. 3. Distribution of predominant prior land use by (a) LSPVP area and (b) number of homes near LSPVPs.

(b) the proportion of transactions near LSPVPs by predominant prior land use type.

Step 2: For each home we calculated the geodesic distance to the polygon boundary of the nearest LSPVP and to all A/D locations. We also determined underlying A/D characteristics, where appropriate, such as flood zone status and road/airport sound levels. Finally, we determined the urbanicity of each home's location. Fig. 4 shows the distribution of homes by state and urban, urban cluster, or rural designation.

Step 3: We validated the coordinates of select homes[3] that were sited near LSPVPs or A/D using the Google Geocoding API (Google Maps Platform, n.d.), which takes as input an address and returns a set of coordinates as well as a precision indicator. We dropped from our analysis any home transactions where there was inconsistency in the coordinates between CoreLogic and the Google Geocoding API. For some homes, we replaced the CoreLogic coordinates with coordinates from the Google Geocoding API where Google returned a high precision indicator.[4]

Step 4: Given validated coordinates and distances, we retained only the home transactions that were suitable for use in the final analysis. Specifically, we eliminated (1) properties that host a LSPVP (i.e. their coordinates fall within the boundaries of a LSPVP polygon), (2) properties that are over four miles away from a LSPVP, and (3) properties that transacted over 6 years before or after the operation start date of a LSPVP. We also calculated three sets of key values used in the analysis: the transaction's project cohort, LSPVP distance bin, and years since LSPVP construction.

The project cohort refers to the unique ID of the LSPVP that is nearest to a home transaction within 4 miles, and for which the operation start date occurred up to 6 years before or after a LSPVP began construction. If a given transaction belonged to more than one cohort, we retained only the nearest project cohort for that transaction.[5] The distance between the transacted home and the nearest LSPVP was binned into 4 categories: [0 mi, 0.5 mi), [0.5 mi, 1 mi), [1 mi, 2 mi), and [2 mi, 4 mi]. To calculate the number of years since LSPVP construction, we subtracted the LSPVP year of construction start from the sale year (recall that the construction start year is assumed to be the operation start year minus 1 year). The years since LSPVP construction were categorized into 1-year bins (i.e. a sale occurred [−5 years, −4 years), [−4 years, −3 years), ...,[5 years, 6 years), [6 years, 7 years] since LSPVP construction). Our final analytic dataset consists of 1,836,053 transactions near 1,522 different LSPVPs.

Table 2 and Fig. 5 summarize the number of transactions, and the number and size of LSPVPs, respectively, by state. The final dataset contains a number of continuous and categorical property and transaction characteristics (e.g. sale price, sale year, number of bathrooms). Summary statistics for those continuous variables are shown in Table 3 for all six states; summary statistics for individual states are shown in Table A.3 to Table A.8. The categorical property characteristic variables are listed in Table A.9. Finally, Fig. 6 shows the total number of transactions within each distance bin by years since LSPVP construction and indicates that the sample has a robust set of transactions in all distance bins throughout the full sample period. While the home-level

[3] We selected properties that were <0.5 miles from an LSPVP or A/D; within a flood zone with at least 1% chance of flooding, or within an area with road or aviation noise exceeding 55 dB. Of the properties that satisfied these conditions, only those with an area greater than 1 acre or those with missing or non-unique coordinates were validated.

[4] We dropped home transactions from our analysis if the difference between the coordinates provided by the Google Geocoding API and CoreLogic was greater than 2 times the distance between that home and its nearest PV plant or A/D. We additionally dropped any duplicate coordinates within 0.5 mi of a PV plant. Where the Google Geocoding API returned a "rooftop" precision indicator, we replaced the CoreLogic coordinates with Google coordinates; for those homes, we recalculated distances to LSPVP and A/D using the process described in Step 2.

[5] In other words, if transaction T_1 is 0.5 miles from $LSPVP_1$ and 2 miles from $LSPVP_2$, and transacted within 6 years of the operation start date of both $LSPVP_1$ and $LSPVP_2$, we consider transaction T_1 to belong to the $LSPVP_1$ project cohort.

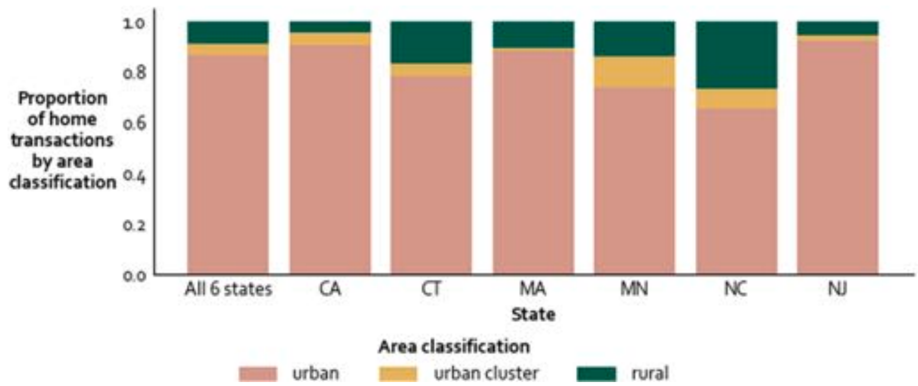

Fig. 4. Distribution of urban, urban cluster, and rural classifications by number of home transactions.

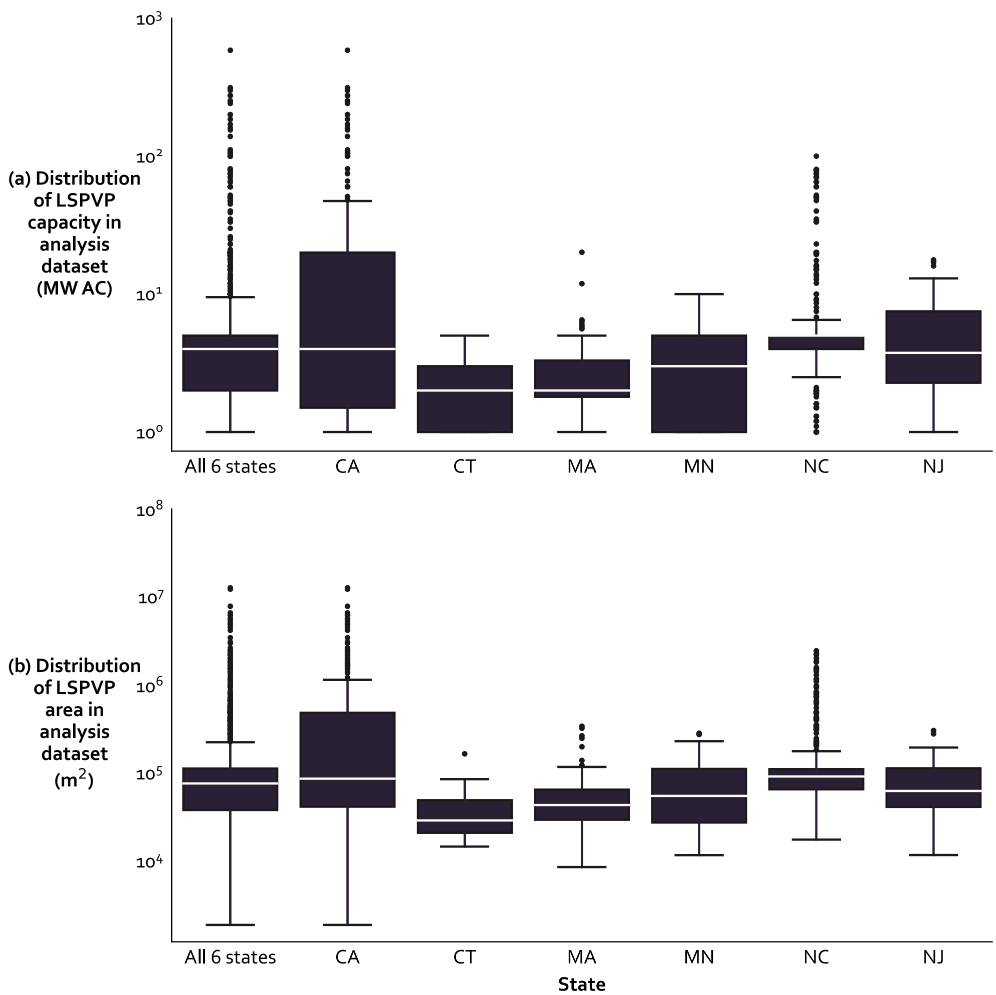

Fig. 5. Distribution of (a) capacity in MW AC and (b) ground-mount area in m^2 of unique LSPVPs in analysis dataset by state. Line represents median value; box limits represent 1st to 3rd quartiles; whiskers represent 4x the inter-quartile range.

transaction data used in this study is protected by a non-disclosure agreement and cannot be made publicly available, our dataset of LSPVP locations and associated sizes and prior land uses is available on Github (Elmallah et al., 2022).

3.2. Model specifications

3.2.1. Base difference-in-difference model

To examine the relationship between LSPVPs and residential property values we utilized a difference-in-differences (DiD) identification strategy that relates the timing of treatment (being close to an LSPVP post construction) to home prices for homes located [0 mi, 0.5 mi), [0.5 mi, 1 mi), and [1 mi, 2 mi) away from a LSPVP. Specifically, we first created 1,522 unique datasets, each representing a unique LSPVP and the residential home transactions that occurred within four miles of the LSPVP and transacted within 6 years before or after the first year of operation of the LSPVP. We call each of these unique datasets a “project cohort.” We then stacked the 1,522 project cohorts to create our final

Table 3
Summary of dependent variables and property and transaction characteristics in full analysis dataset.

Variable	Description	Mean	Std. dev.	Min.	Med.	Max.
Sp	Sale price ($)	$406,552.22	$340,123.75	$5050.00	$321,000.00	$3,998,000.00
Lsp	log of sale price	12.65	0.74	8.53	12.68	15.2
Lsf	Living area (ft^2)	1936.53	1002.05	102	1720.00	120,215.00
acres	Land area (acres)	0.455	0.873	0.006	0.19	14.14
Age	Age of home at time of sale (years)	44.08	30.86	0	40	212
agesq	Age of home at time of sale, squared ($years^2$)	2895.66	3708.86	0	1600.00	44,944.00
salesqtr	Quarter of sale	2.27	0.87	1	2	4
salesyr	Year of sale	2015	3	2003	2015	2020

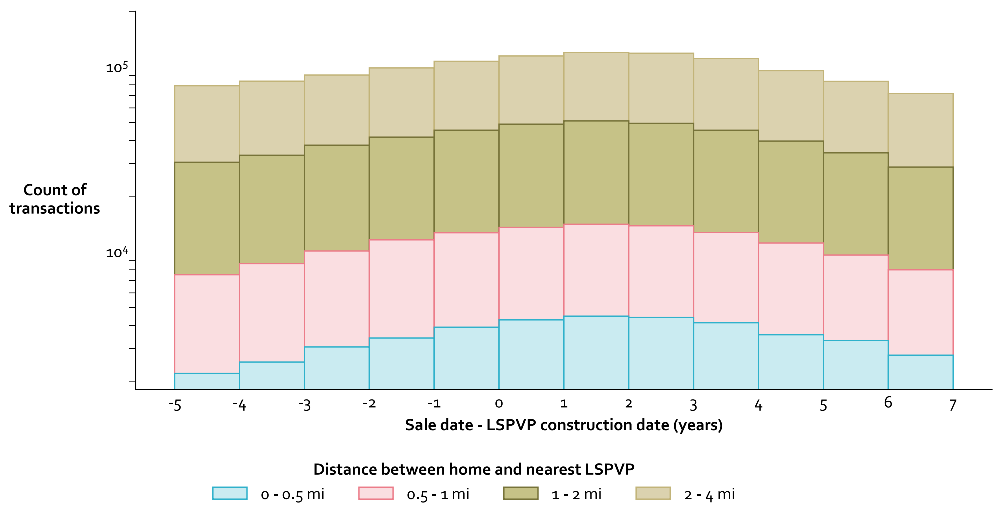

Fig. 6. Count of transactions in final analysis dataset by distance between transacted home and nearest LSPVP.

analytic dataset and specify a stacked difference-in-differences specification of the following form:

$$ln\left(P_{icdjqt}\right) = \beta\, \boldsymbol{T}_{idt} + \boldsymbol{X}_i\alpha + \delta_{dc} + \lambda_{tc} + \rho_{qc} + \varphi_j + \varepsilon_{icdjqt} \quad (1)$$

The dependent variable in (1) is the natural log of sales price P for residential home transaction i that belongs to a project cohort c within distance bin d and census block group j, that transacted in quarter q of year t. T_{idt} is a vector consisting of 3 distance bin indicators for homes located [0 mi, 0.5 mi), [0.5 mi, 1 mi), [1 mi, 2 mi) from a LSPVP, where each distance bin is interacted with an indicator for whether the home sale occurred after LSPVP construction. The omitted category for the distance bin indicators is homes located 2 to 4 miles from a LSPVP. δ_{dc}, λ_{tc} *and* ρ_{qc} are, respectively, distance bin-by-project cohort fixed effects (FEs), transaction year-by-project cohort FEs and transaction quarter-by-project cohort FEs. φ_j is a vector of census block group FEs, and ε_{icdjqt} is a random disturbance term. Finally, X_i is a vector of individual home characteristics including living square footage, land area, the age of the home at the time of sale, age squared, the number of full bathrooms and stories, the type of air conditioning (AC) and heating, the construction type and exterior wall type of the home, indicators for fireplaces and new construction, the type of garage, and the type of view a home has. The standard errors in (1) are clustered at the project cohort level.

The coefficients of primary interest in (1) are the β s which represent the DiD estimates of the effect of treatment (being close to an LSPVP post construction) on home prices for homes located [0 mi, 0.5 mi), [0.5 mi, 1 mi), and [1 mi, 2 mi) away from an LSPVP, respectively. Our DiD identification strategy is both transparent and intuitive. Specifically, each of the 1,522 project cohorts represents a unique quasi-experiment where the treatment group is homes located within [0 mi, 0.5 mi), [0.5 mi, 1 mi), and [1 mi, 2 mi) from a LSPVP and the control group is homes located 2 to 4 miles from a LSPVP. For each of these 1,522 quasi-experiments, our DiD framework then compares the sale price of homes located close to a LSPVP to the sale price of homes located farther away before and after LSPVP construction. The inclusion of distance bin-by-project cohort FEs, δ_{dc}, transaction year-by-project cohort FEs, λ_{tc}, and transaction quarter-by-project cohort FEs, ρ_{qc}, imply that our estimates are identified based only on within-project cohort variation in sale prices and distance from a LSPVP. Our coefficients of primary interest, β s, therefore represent the average treatment effect over the 1,522 quasi-experiments for homes located within each of our specified distance bins.

Another advantage of our stacked DiD framework is that it avoids the potential biases that can arise in standard DiD and event study models in the presence of staggered timing of treatment with heterogeneous treatment effects. Specifically, several recent studies have shown that DiD specifications relying on the staggered timing of treatment for identification may be biased in the presence of heterogeneous treatment effects due to the contamination of treatment effects from early versus later adopters from other relative time periods (Callaway and Sant'Anna, 2021; Goodman-Bacon, 2021; Sun and Abraham, 2021). As discussed by Cengiz et al. (2019) and Goodman-Bacon (2021), our stacked DiD model avoids this potential source of bias by ensuring that treatment effects are based only on within-project cohort comparisons.

3.2.2. Robustness checks

We investigated the robustness of the base model given by (1) to the choice of spatial FEs, time FEs, and treatment and control categories with three alternative specifications. Our first robustness check added a distance bin for homes located within 0.25 miles of a LSPVP.

Specifically, we augmented the distance bins in (1) to include four (rather than three) indicators for homes located in the [0 mi, 0.25 mi),[6] [0.25 mi, 0.5 mi), [0.5 mi, 1 mi), and [1 mi, 2 mi) distance bins; the indicator equals 1 if a transaction occurred within that distance bin in the same year or after LSPVP construction started, and 0 otherwise. This specification allows us to investigate the presence of a home price effect at even smaller distances. In our second robustness check we replaced the year-by-project cohort and quarter-by-project cohort FEs in the base model by a single vector of quarter-by-year-by-project cohort FEs to allow for more granular trending of home values across quarters and years. In our third robustness check we added the vector of A/D variables, consisting of distance and value bins described in section 3.1 to account for any potential correlation between the A/D variables and the timing and location of a LSPVP that may bias our base model estimates.[7]

3.2.3. Event study model

In addition to the base model specification in (1), we specified an event-study model, which allowed us to test the parallel trends assumption underlying the difference-in-differences model and to allow treatment effects to evolve non-parametrically post-construction. Specifically, we estimated a model of the following form:

$$\ln\left(P_{icdjqtk}\right) = \sum_{k=-5}^{7} T_{k,idt}\gamma_k + \boldsymbol{X}_i\kappa + \delta_{dc} + \lambda_{tc} + \rho_{qc} + \varphi_j + \eta_{icdjqtk} \tag{2}$$

where $T_{k,idt}$ represents a series of lead and lag indicators for when a LSPVP began construction for each of the three distance bins defined in (1). We re-centered $T_{k,idt}$ so that $T_{0,idt}$ always equals one in the year the LSPVP began construction. We included a series of indicators from 1 to 5 years prior to a LSPVP being constructed ($T_{-5,idt}$ to $T_{-1,idt}$), and a series of indicators for 1–7 years after construction ($T_{1,idt}$ to $T_{7,idt}$). The omitted category for our treatment indicators (i.e. the reference year for all estimates) is the year of construction start for a LSPVP ($T_{0,idt}$). $\eta_{icdjqtk}$ is a random disturbance term and all other terms are as defined in (1).

The coefficients of primary interest in (2) are the $\gamma_k^{'}s$. The estimated coefficients on the lead treatment indicators ($\gamma_{-5}, \ldots, \gamma_{-1}$) indicate whether the parallel trends assumption, which underlies all causal claims based on DiD models, appears to hold. Specifically, if LSPVP installation induces exogenous changes in home values, these lead treatment indicators should be small in magnitude and statistically insignificant, implying that the price of homes located close to a LSPVP (within 2 miles) were trending in a similar way to homes located farther away (2 to 4 miles) prior to LSPVP construction. The lagged treatment indicators ($\gamma_1, \ldots, \gamma_7$) allow the effect of distance to a LPSVP on home prices to evolve over time in the post treatment period in a non-parametric way.

3.2.4. Heterogeneity analyses

We conduct four heterogeneity analyses using the baseline model given by (1). First, we examined potential heterogeneity across states by estimating (1) separately for each of the six states in our sample. Second, we investigated the relationship between prior LSPVP land use and property value impacts by dividing our sample into four groups: home transactions near LSPVPs that were predominantly agricultural, greenfield, brownfield, or mixed land use prior to LSPVP construction. Third, we investigated the relationship between urbanicity and property value impacts by dividing our sample into one of the following U.S. Census Bureau designations: urban, urban clusters, or rural. Finally, we investigated the relationship between project size (area in square meters) and property values by applying the base model (1) to two subsets of the data: home transactions near LSPVPs below the 50th percentile of LSPVP areas and above the 50th percentile of LSPVP areas, where the 50th percentile is calculated from the set of unique LSPVPs in our sample.

4. Results

4.1. Base model and robustness check results

Table 4 shows results for the base model given by (1) and the robustness checks described above. As shown in column 1, we find an average 1.5% reduction in house prices for homes within 0.5 miles of a LSPVP that transacted post-LSPVP construction, and an average 0.82% reduction in home prices for homes 0.5–1 mi away from a LSPVP. Both estimates are statistically significant at the 5 percent level or better. As shown in column 2, we additionally find an average 2.3% reduction in home prices within 0.25 mi of a LSPVP. In both models, the estimated treatment effects for homes located 1 to 2 miles from a LSPVP are quite small in magnitude and statistically insignificant, suggesting that the impact of LSPVPs on home values fades relatively quickly with distance from a LSPVP. Further, all effects are monotonically ordered from closest distances to further away, which meets a priori expectations and provides us additional confidence in the model. As shown in columns 3 and 4 of Table 4, altering the time FEs by including quarter-by-year-by-project cohort FEs or controlling for other A/D does not notably alter the estimates from the base model.

4.2. Event study results

In Fig. 7 we present results from our event study specification given by (2), with coefficient estimates of our three distance bins shown as lines, and 95% confidence intervals shaded in similar colors. Homes located 2–4 miles from a LSPVP are once again the omitted category. Despite some noise in the estimates based on sales that occurred four or five years prior to LSPVP construction, in general there is very little evidence that home values were trending lower prior to the construction of a LSPVP: all of the estimated pre-treatment effects are small in magnitude and statistically insignificant. The lack of differential trending prior to the installation of a LSPVP provides evidence that our main identification assumption—the parallel trends assumption—holds. Fig. 7 also shows a relatively clear decline in home values that starts shortly after the beginning of LSPVP construction and continues up to six years post construction. The negative impact of LSPVPs on home values is particularly pronounced for homes located 0 to 0.5 miles from a LSPVP where we see home values declining by 4 percent six years after LSPVP construction.[8]

4.3. Heterogeneity analyses results

Fig. 8 shows results from all the heterogeneity analyses alongside the base model results; for ease of visualization, only the coefficients and 95% confidence interval for the 0–0.5 distance bin are shown, while Table 5 through Table 8 show more detailed results for each heterogeneity analysis. As shown in Table 5, which shows base model results for individual states, changes in sales price are not statistically significant for CA, CT, and MA. However, MN, NC, and NJ, show a statistically

[6] A total of 6,252 transactions occurred both within 0.25 mi of an LSPVP and after that LSPVP was constructed.

[7] For A/D distance bins, the omitted category is [2 mi, 4 mi) from a home; for noise levels, the omitted category is the <45 dB category; for flood zone, the omitted category is the missing category.

[8] When investigating results for individual states, both for the event study (section 3.2.3) and the heterogeneity analyses (section 3.2.4), our results largely agreed with the results for the full 6 state sample. However, our individual state estimates suffer from small sample sizes in individual time and distance categories for the event study and in individual subcategories for the heterogeneity analyses, so results are less reliable. Therefore, we do not present them in this paper. Results for individual states are available upon request from the authors.

Table 4
Average effect of LSPVP construction and proximity on home prices for all six states. Standard errors are clustered at the project cohort level and are in parentheses. Significance levels: ***p < 0.01, **p < 0.05, *p < 0.1

Dependent variable: the logarithm of house prices	Base model (1)	Including 0–0.25 mi distance bin	Including quarter-year-project cohort FEs	Including amenities and disamenities vector
Distance between home and LSPVP: [0 mi, 0.25 mi)		−0.0226*** (0.00767)		
Distance between home and LSPVP: [0.25 mi, 0.5 mi)		−0.0133** (0.00641)		
Distance between home and LSPVP: [0 mi, 0.5 mi)	−0.0154** (0.00630)		−0.0171*** (0.00642)	−0.0170*** (0.00589)
Distance between home and LSPVP: [0.5 mi, 1 mi)	−0.00820** (0.00413)	−0.00820** (0.00413)	−0.00941** (0.00424)	−0.00987** (0.00403)
Distance between home and LSPVP: [1 mi, 2 mi)	−0.000841 (0.00226)	−0.000841 (0.00226)	−0.00179 (0.00234)	−0.00131 (0.00225)
Home characteristics	✓	✓	✓	✓
Distance-project cohort FEs	✓	✓	✓	✓
Sale year-project cohort FEs	✓	✓		✓
Sale quarter-project cohort FEs	✓	✓		✓
Census block group FEs	✓	✓	✓	✓
Sale year-sale quarter-project cohort FEs			✓	
Amenities and disamenities				✓
Observations	1,832,888	1,832,888	1,826,915	1,778,533
R^2	0.835	0.835	0.839	0.835

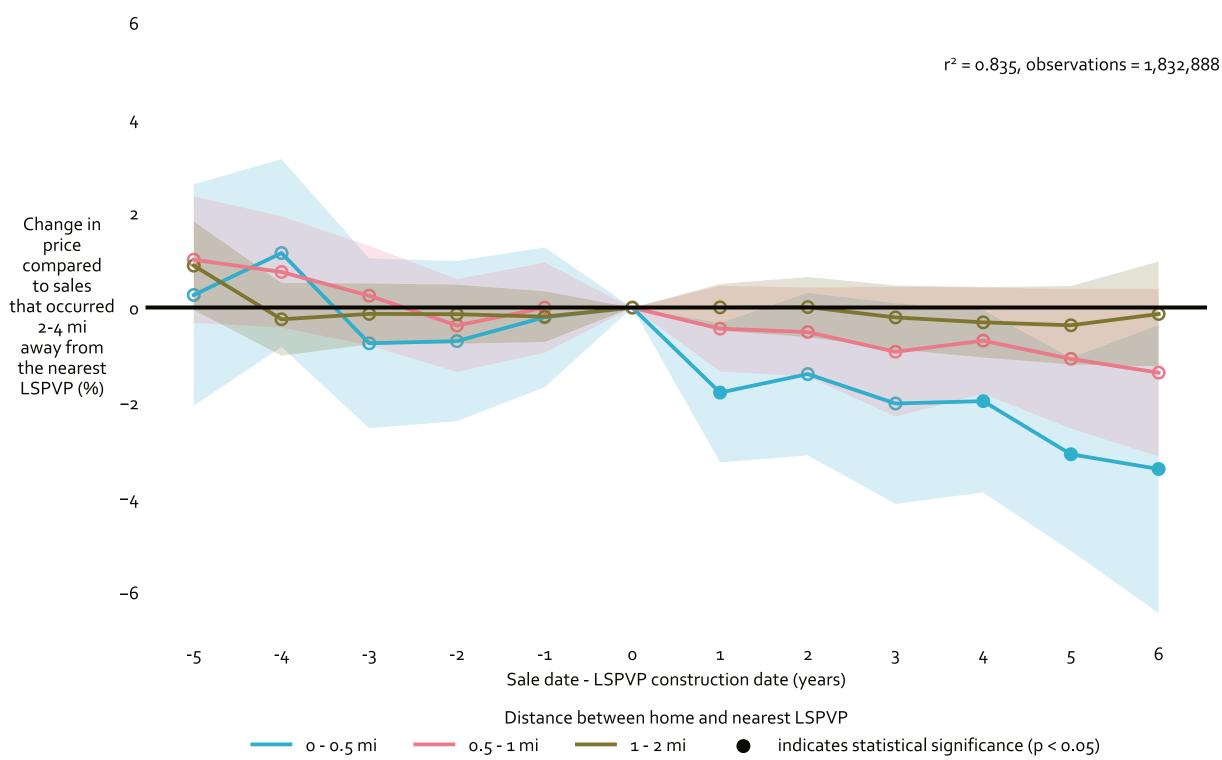

Fig. 7. Average effect of proximity to LSPVP by year of sale relative to year of LSPVP construction; shaded area represents 95% confidence interval; x-axis label represents lower bound of year range (e.g. −5 refers to all transactions that occurred [-5, −4) years before the construction date of the nearest LSPVP).

significant negative effect of 4%–5.6%, more than double that of the average across all states in the base model. In Table 6, where we examine potential heterogeneity by predominant prior land use of the nearest LSPVP,we find that statistically significant home value reductions are only observed for homes nearest to LSPVPs that are sited on previously agricultural land.[9] These findings are consistent with the results in

[9] We also tested the base model for a sample of only homes nearest to LSPVPs on previously forested land (NLCD classes of Deciduous Forest, Evergreen Forest, or Mixed Forest) and found no statistically significant results with p < 0.1.

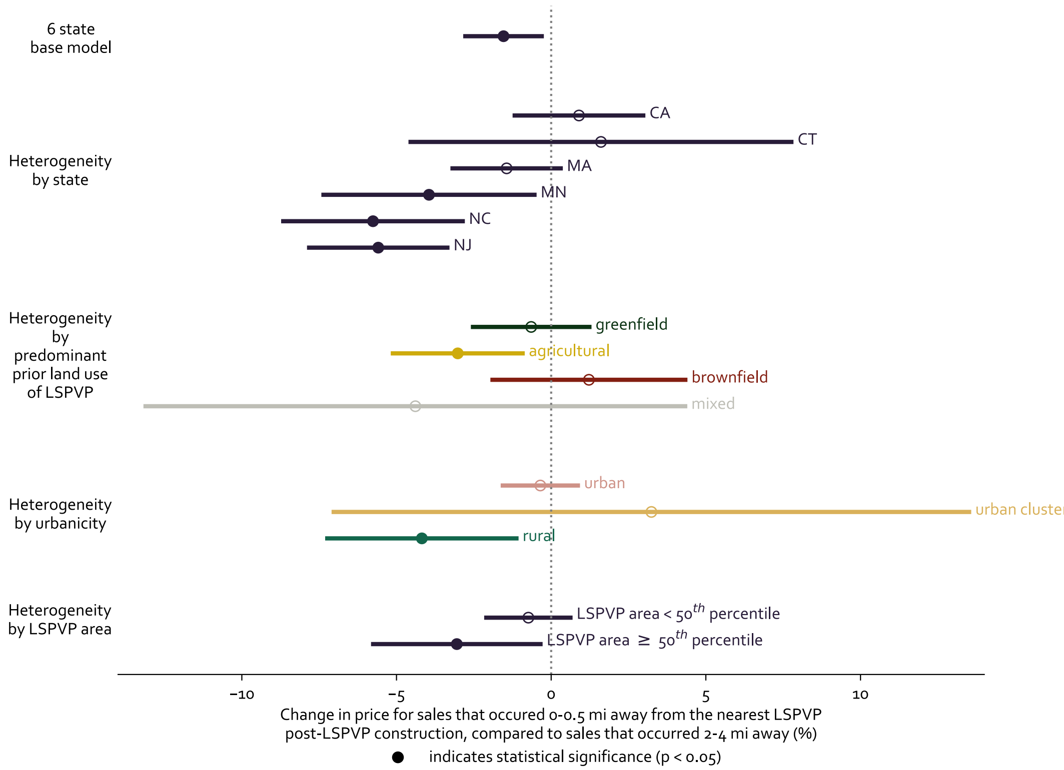

Fig. 8. Results from base model as well as each heterogeneity analysis, showing average effect of LSPVP construction and proximity for homes 0–0.5 mi away from nearest LSPVP. Range of change in price represents the 95th percent confidence interval.

Table 5
Effect of LSPVP construction and proximity on home prices in individual states, using base model specification. Standard errors are clustered at the project cohort level and are in parentheses. Significance levels: ***p < 0.01, **p < 0.05, *p < 0.1

Dependent variable: the logarithm of house prices	CA	CT	MA	MN	NC	NJ
Distance between home and LSPVP: [0 mi, 0.5 mi)	0.00899 (0.0106)	0.0161 (0.0314)	−0.0144 (0.00892)	−0.0395** (0.0174)	−0.0576*** (0.0148)	−0.0559*** (0.0114)
Distance between home and LSPVP: [0.5 mi, 1 mi)	0.000849 (0.00696)	0.0234 (0.0150)	−0.00933** (0.00469)	−0.0209** (0.00932)	−0.0473*** (0.0118)	−0.0135* (0.00698)
Distance between home and LSPVP: [1 mi, 2 mi)	0.00296 (0.00384)	0.0186** (0.00786)	−0.00190 (0.00319)	−0.0108* (0.00625)	−0.0117** (0.00570)	−0.00487 (0.00331)
Observations	931,735	34,135	291,403	74,905	203,005	297,677
R^2	0.881	0.774	0.777	0.708	0.735	0.751

Table 6
Average effect of LSPVP construction and proximity on home prices by predominant prior land use of nearest LSPVP to home, using base model specification. Standard errors are clustered at the project cohort level and are in parentheses. Significance levels: ***p < 0.01, **p < 0.05, *p < 0.1

Dependent variable: the logarithm of house prices	Greenfield	Agricultural	Brownfield	Mixed
Distance between home and LSPVP: [0 mi, 0.5 mi)	−0.00646 (0.00960)	−0.0302*** (0.0107)	0.0122 (0.0159)	−0.0439 (0.0445)
Distance between home and LSPVP: [0.5 mi, 1 mi)	−0.000991 (0.00480)	−0.0202*** (0.00629)	−0.00909 (0.0170)	−0.00679 (0.0342)
Distance between home and LSPVP: [1 mi, 2 mi)	0.000836 (0.00248)	−0.00408 (0.00498)	−0.00483 (0.00739)	−0.000377 (0.0191)
Observations	1,074,492	577,769	147,951	12,987
R^2	0.843	0.833	0.860	0.828

Table 7
Average effect of LSPVP construction and proximity on home prices by home urban, urban cluster, or rural designation, using base model specification. Standard errors are clustered at the project cohort level and are in parentheses. Significance levels: ***p < 0.01, **p < 0.05, *p < 0.1

Dependent variable: the logarithm of house prices	Rural	Urban cluster	Urban
Distance between home and LSPVP: [0 mi, 0.5 mi)	−0.0418*** (0.0156)	0.0324 (0.0524)	−0.00350 (0.00619)
Distance between home and LSPVP: [0.5 mi, 1 mi)	−0.0201* (0.0119)	0.0221 (0.0316)	−0.00342 (0.00437)
Distance between home and LSPVP: [1 mi, 2 mi)	0.00775 (0.00613)	−0.00597 (0.00896)	0.00137 (0.00222)
Observations	151,792	79,279	1,592,715
R^2	0.803	0.785	0.845

Table 8
Average effect of LSPVP construction and proximity on home prices by area of LSPVP, using base model specification. Standard errors are clustered at the project cohort level and are in parentheses. Significance levels: ***p < 0.01, **p < 0.05, *p < 0.1

Dependent variable: the logarithm of house prices	LSPVP area < 50th percentile of area (75,138 m^2)	LSPVP area ≥ 50th percentile of area (75,138 m^2)
Distance between home and LSPVP: [0 mi, 0.5 mi)	−0.00737 (0.00694)	−0.0305** (0.0138)
Distance between home and LSPVP: [0.5 mi, 1 mi)	−0.00483 (0.00521)	−0.0166** (0.00684)
Distance between home and LSPVP: [1 mi, 2 mi)	0.00225 (0.00287)	−0.00841** (0.00344)
Observations	1,291,762	537,189
R^2	0.841	0.833

Table 7, which shows that statistically significant effects were only observed for homes located in rural areas. Finally, in Table 8 we examine potential heterogeneity in property value impacts by the size of a LSPVP project. Specifically, we split the sample based on LSPVP areas and estimate separate models for homes located near LSPVPs that are above or below the median LSPVP area in our sample. Adverse effects are only observed for LSPVPs with an area larger than the median area of all unique LSPVPs in our sample[10].

5. Discussion

In this paper, we add to the growing body of research on the impact of LSPVPs on residential home values. By assembling an analysis dataset consisting of transaction data, an original dataset of LSPVP footprints, a suite of environmental amenities and dis-amenities, urbanicity classifications, and historic land cover data, we answer two related research questions.

First, we ask: what effect, if any, do LSPVPs have on residential home prices? Across the six states in the study area, we observe that homes within 0–0.5 mi of an LSPVP that transact after a LSPVP is constructed decline in sale price by an average of 1.5% compared to homes 2–4 mi away. At closer distances of 0–0.25 mi, the average decline in property values is 2.3%. This effect fades at further distances from a LSPVP; we observe a small adverse effect for homes 0.5–1 mi away of 0.8%, and no evidence of an effect at distances beyond 1 mi. Our estimates are robust to choices of time FEs and we control for other landscape characteristics that could impact property values. Our results are consistent with some prior literature (Dröes and Koster, 2021; Gaur and Lang, 2020) that find an overall adverse impact of LSPVP construction on property values.

Second, we ask: does the effect of LSPVPs on home prices differ based on the state, the prior land use on which a LSPVP is located, the size of the LSPVP, or the urbanicity of a home? When looking at individual states in our sample, we observe no effect on sales prices in CA, CT, and MA, but find sale price reductions for homes 0–0.5 mi away from a LSPVP of 4%, 5.8%, and 5.6% in MN, NC, and NJ, respectively. In those states where we do observe sale price reductions, the effect fades as distances from an LSPVP increases, as with the full 6 state model. When separating transactions by the prior land use and the area of the LSPVP to which they are closest, as well as by the urbanicity of the home, we observe statistically significant effects only for transactions near LSPVPs sited on previously agricultural land, transactions in rural areas, and transactions near larger LSPVPs by area. We observe decreases of 3%, 4.2%, and 3.1% for homes within 0–0.5 mi of LSPVPs on previously agricultural land, in rural areas, or near large LSPVPs, respectively, compared to homes 2–4 mi away. In all three cases, these effects fade with distance from a LSPVP. We observe no statistically significant effect of LSPVP construction and proximity on home prices in other categories for land use (greenfield, brownfield, or mixed land use sites), urbanicity (urban or urban cluster regions), or LSPVP area (where areas fall below the median LSPVP area in our dataset). Looking at the heterogeneity results by land use and urbanicity may help us understand the heterogeneity we observe by state: the states where we observe no statistically significant difference in sales price (in CA, CT, and MA) are also the states with lower proportions of LSPVP development on agricultural land (Fig. 3). CA additionally has very few transactions in rural areas (Fig. 4).

Our heterogeneity analyses show that the property value impacts of LSPVP development are highly contextual, and reinforce scholarly arguments that research on public support for solar energy should consider both project scale and proposed locations (Nilson and Stedman, 2022). Specifically, our results point to the importance of understanding the perceptions, economic impacts, and social dynamics of larger solar developments, rural developments, and developments built on previously agricultural land. Broader social science scholarship can contextualize these results: for instance, researchers have theorized that the siting of renewable energy in rural areas can counter personal, cultural, and political representations and understandings of rural landscapes (Batel et al., 2015). Our observed heterogeneity may reflect how large, agricultural, or rural developments potentially conflict more directly with those representations than smaller, non-agricultural, or urban developments. Furthermore, our results with respect to land use connect to an emerging literature on the co-location of solar and agriculture: surveys show that residents in agricultural communities are more likely to support solar development that integrates agricultural production (Pascaris et al., 2022), though scholarly reviews note that our understanding of perceptions of solar-agricultural systems remains limited (Mamun et al., 2022).

6. Limitations and future work

A key limitation of our research approach is that we consider only one aspect of the economic impacts of LSPVPs: property values. The impacts of local energy development are also shaped by local tax revenue and employment impacts, which have consistently been found to result in positive benefits (Brunner et al., 2021; Brunner and Schwegman, 2022a, 2022b), as well as by LSPVP ownership structures. This implies that homeowners can and do capitalize the positive impacts of renewable energy into home prices. Because this analysis compared home prices between homes around the same projects, any differences in value as compared to homes not near any LSPVP, and thus not subject to local tax or employment impacts, would have remained undiscovered. Furthermore, to the extent that property value changes reflect the revealed preferences of residents, they only reflect the preferences of the subset of residents who are homeowners. Where homeownership rates are lower – largely in urban areas, but in an increasing portion of rural areas as well (Pendall et al., 2016) – property value changes may not reflect the preferences of neighbors to the extent that they do where homeownership rates are higher. Considering these varied economic impacts would necessitate methodologies and data collection beyond the hedonic DiD analysis used in this paper.

These limitations suggest two major avenues for future work. First, more research attention is needed on the economic impacts of LSPVPs, broadly understood to encompass dimensions such as tax revenue, ownership structures, or employment. Added research on the local economic impacts of LSPVPs can position our findings on the average

[10] We also tested the base model for two additional samples: homes near very large LSPVPs (areas greater than the 75th percentile of areas of unique LSPVPs in our sample) and near very small LSPVPs (areas below the 25th percentile of areas of unique LSPVPs in our sample). For both subsets of our data, we found no statistically significant results with p < 0.1.

adverse impact of LSPVP development on home prices in a broader context of economic benefits and burdens due to LSPVP development. Second, more research is needed to understand the heterogeneity that we observe with respect to larger, agricultural, and rural LSPVPs. Here, surveys, qualitative research, mixed-methods, and case study-based approaches may indicate how neighbors of LSPVPs engage differently with their nearby solar installation based on its size, land use, or the urbanicity of their home.

7. Conclusion and policy implications

This paper provides some of the first comprehensive evidence on the impact of LSPVPs on residential home values. Specifically, we ask: (1) what effect, if any, do LSPVPs have on residential home prices and (2) does the effect of LSPVPs on home prices differ based on the prior land use on which an LSPVP is located, the size of the LSPVP, or the urbanicity of a home? In our six-state study area (CA, CT, MA, MN, NC, NJ), we find that homes within 0.5 mi of LSPVP experience an average home price reduction of 1.5% compared to homes 2–4 mi away; statistically significant effects are not measurable over 1 mi from a LSPVP. These effects are only measurable in certain states (MN, NC, and NJ), for LSPVPs constructed on agricultural land, for larger LSPVPs, and for rural homes.

Our study extends the existing literature in three ways. First, we consider a larger sample, both in terms of transactions and LSPVPs, than prior studies. Our six-state study area encompasses 53% of the total MW nameplate capacity of PV generators in the U.S., and our analysis included evidence from over 1,500 LSPVPs and over 1.8 million home transactions. The scope of our dataset allows us to provide average impact estimates for a much larger set of LSPVP projects within the United States. Second, to our knowledge, our study is the first study on LSPVP property values impacts to use a dataset of LSPVP footprints (as opposed to point locations or approximations of LSPVP area using circular buffers). By constructing and using footprint data, we can more precisely assess the land area and prior land use of LSPVPs, as well as reduce measurement error when calculating distances between homes and a LSPVP. Finally, we employ a stacked DiD specification with bin-by-project cohort FEs, which not only advances the methodology used for this type of analysis but also addresses recent concerns over DiD specifications that rely on staggered timing of treatment.

Our findings have two main policy implications. First, they point to the need for policy and development measures to ameliorate possible negative impacts of LSPVP development in some contexts. Our results suggest that there are adverse property value impacts of LSPVP construction for homes very close to a LSPVP and those predominantly in rural agricultural settings around larger projects. But we find that most impacts fade at distances greater than 1 mile from a LSPVP. In some cases – for homes near large LSPVPs, and in the states of MN and NC – negative effects persist at distances greater than 1 mile but are smaller than they are at nearer distances to a LSPVP. These results suggest that care should be taken in siting LSPVPs near homes in some contexts. Developers or policymakers considering siting LSPVPs very close to homes have several tools to employ, such as compensation schemes with neighbors and landscape measures like vegetative screening.

Second, the heterogeneity analyses reveal the importance of place and project-specific assessments of LSPVP development practices. Although we find adverse impacts of LSPVP construction on property values overall, we notably find no evidence of impacts in three states in our study area – including in CA, which alone accounts for over half of the transactions in our dataset. On the other hand, we do see evidence of adverse property value impacts of LSPVPs in the other three states in our dataset – including in MN, despite MN having arguably the most restrictive state-wide laws on LSPVP development in high-value agricultural areas of the states in our study area (Bergan, 2021). While our sample for individual states was too small to conclusively explore heterogeneity within states, our overall heterogeneity analysis suggests that adverse impacts of LSPVP development are present specifically in rural areas, where LSPVP displaces agricultural land uses, and where LSPVP installations are larger. For policy-makers, this heterogeneity may point to the importance of carefully considering siting strategies for rural, large, or agricultural installations – for instance, by exploring ways to co-locate agricultural land uses and solar development. However, this heterogeneity does not mean that economic impacts are negligible where property value impacts were insignificant (CA, CT, MN, as well as urban, non-agricultural, and smaller developments): as discussed in section 6, many economic impacts remain undiscovered by our methodology, some of which might increase home values, and future policy-relevant research is needed to understand the economic impacts of LSPVPs, broadly construed.

By combining a novel dataset of LSPVP footprints with home transaction data, our analysis provides comprehensive evidence that LSPVPs have an average adverse effect on home prices, but notably shows that these impacts are not uniform across geographies, land uses, or LSPVP size. In doing so, we contribute to the emerging literature on the economic impacts of LSPVPs and point to important avenues for future policy discussions and research.

CRediT authorship contribution statement

Salma Elmallah: Conceptualization, Methodology, Formal analysis, Data curation, Writing. **Ben Hoen:** Conceptualization, Methodology, Formal analysis, Writing, Project administration, Supervision, Funding acquisition. **K. Sydny Fujita:** Methodology, Formal analysis, Data curation, Writing. **Dana Robson:** Data curation, Writing. **Eric Brunner:** Conceptualization, Methodology, Formal analysis, Writing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Datasets related to this article that can be shared can be found at https://zenodo.org/record/7415662.

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Appendix

Table A.1
Retention criteria for transactions

Condition for retention	Rationale
Coordinate values are populated	Coordinates are needed to obtain distances between homes and LSPVP, amenities, and dis-amenities
Land area, year built, and home square footage are populated	Land area, year built, and home square footage are essential property characteristics to control for in analysis
Coordinates appear 20 times or less	Repeated, identical coordinates for multiple properties may indicate data quality issue
Property type is residential (including single family residence, condominium, duplex, apartment)	Analysis only considers homes (i.e. residential properties) sold in arms length transactions after the year 2000
Transaction is categorized as arms length	
Year of sale between 2000 and 2021	
Sale amount is greater than $5000 or the 1st percentile of sale price (whichever value is higher) and less than the 99th percentile of sale amount values within a given state	Removing outliers from analysis
Sale amount per unit area of living space is greater than the 1st percentile and less than the 99th percentile of sale amount per unit area of living space values within a given state	
Land area is greater than the 1st percentile and less than the 99th percentile of land area values within a given state	
Property was built before 2020, and after the 1st percentile of values for year built within a given state	
Sale amount is greater than the mortgage amount, or mortgage amount is missing	Any other relationship (between sale amount & mortgage amount, land area & living space area, sale year & year built, set of variables representing land area) may indicate data quality issues
Land area is greater than living space area	
Age of property (sale year minus year built) is non-negative	
Both variables representing land area converge within 0.01 acres	
Deed is not categorized as foreclosure	Sale amount in a foreclosure may not accurately represent the value of a home
Sale occurred over one year after last recorded sale for that property	Removes potentially "flipped" homes, or homes that undergo a rapid renovation and are re-sold, from dataset; for those homes, characteristics in CoreLogic dataset may not be representative of characteristics after renovation
Property address was not determined from mail	Address determined from mail may reflect the address of an absentee owner, not of the physical property location

Table A.2
Amenity and dis-amenity data sources

Amenity/dis-amenity	Data source	Data description	Reference
Aviation noise Road noise	U.S. Department of Transportation	Raster representing approximate average noise energy due to transportation noise sources over a 24-h period at the receptor locations where noise is computed, expressed in decibels (dB)	U.S. Department of Transportation (2020)
Flood zones	U.S. Federal Emergency Management Agency	Categorizes areas by likelihood of flood, ranging from minimal risk to 26% chance of flooding over the life of a 30-year mortgage	Federal Emergency Management Agency (2021)
Municipal, industrial, and transfer landfills	U.S. Department of Homeland Security	Provides locations of active permitted municipal solid waste facilities and construction and demolition debris facilities.	Department of Homeland Security (2020)
State and national parks	Esri	Provides boundaries of parks and forests in the United States at the national, state, regional, and local level	Esri (2021)
Nuclear power generation facilities	National Institute of Health	Provides locations of U.S. commercial nuclear power plants	Hochstein and Szczur (2006)
Coal power generation facilities	U.S. Environmental Protection Agency	Facility data (as of 2017) where primary or secondary fuel type is coal-related (e.g., Coal, Coal Refuse, and Petroleum Coke).	U.S. Environmental Protection Agency (2021)
Coastline	ABB Group	Locations of U.S. coastline, including bays, river outlets, and Great Lakes	ABB Group (2020)
Lakes		Locations of U.S. lakes, represented as polygons	
High-voltage lines		Transmission and distribution lines with a voltage of 100 V or greater, represented as polylines	

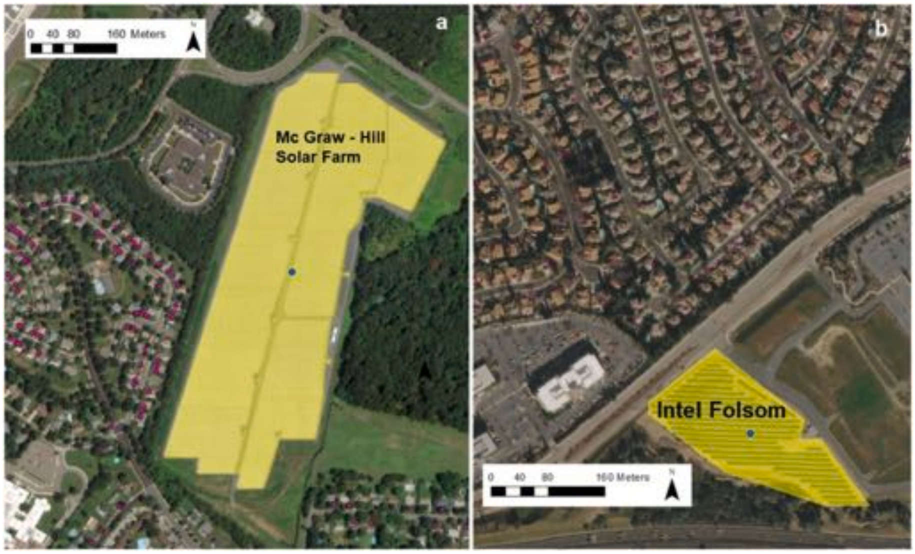

Fig. A.1. Satellite imagery showing examples of LSPVP centroids (blue dots) and polygons (yellow shaded areas) near homes including homes that transacted during our study period (pink dots): (a) McGraw-Hill Solar Farm, NJ and (b) Intel Folsom, CA

Table A.3
Summary of dependent variables and property characteristics, CA

Variable	Description	Mean	Std. dev.	Min.	Med.	Max.
Sp	Sale price ($)	$457,797.53	$403,489.03	$35,500.00	$350,000.00	$3,998,000.00
Lsp	log of sale price	12.75	0.75	10.48	12.77	15.2
Lsf	Living area (ft^2)	1868.69	1026.22	102	1654.00	98,694.00
Acres	Land area (acres)	0.336	0.7	0.018	0.165	7.231
Age	Age of home at time of sale (years)	36.94	24.79	0	34	112
Agesq	Age of home at time of sale, squared (years^2)	1979.42	2233.94	0	1156.00	12,544.00
Salesqtr	Quarter of sale	2.23	0.88	1	2	4
Salesyr	Year of sale	2014	3	2003	2015	2020

Table A.4
Summary of dependent variables and property characteristics, CT

Variable	Description	Mean	Std. dev.	Min.	Med.	Max.
Sp	Sale price ($)	$283,251.18	$184,202.97	$36,000.00	$239,900.00	$1,640,000.00
Lsp	log of sale price	12.4	0.56	10.49	12.39	14.31
Lsf	Living area (ft^2)	1916.21	951.46	196	1669.00	35,170.00
Acres	Land area (acres)	0.818	1.114	0.07	0.41	9.51
Age	Age of home at time of sale (years)	59.74	33.65	0	58	212
Agesq	Age of home at time of sale, squared (years^2)	4700.55	5311.95	0	3364.00	44,944.00
Salesqtr	Quarter of sale	2.32	0.83	1	2	4
Salesyr	Year of sale	2017	2	2011	2018	2020

Table A.5
Summary of dependent variables and property characteristics, MA

Variable	Description	Mean	Std. dev.	Min.	Med.	Max.
Sp	Sale price ($)	$428,122.04	$284,039.71	$5100.00	$360,000.00	$2,199,000.00
Lsp	log of sale price	12.78	0.63	8.54	12.79	14.6
Lsf	Living area (ft^2)	2019.36	961.96	173	1802.00	35,721.00
Acres	Land area (acres)	0.584	0.764	0.03	0.315	6.6
Age	Age of home at time of sale (years)	62.74	38.25	0	58	209
Agesq	Age of home at time of sale, squared (years^2)	5399.73	5906.47	0	3364.00	43,681.00
Salesqtr	Quarter of sale	2.35	0.84	1	2	4
Salesyr	Year of sale	2015	3	2005	2016	2020

Table A.6
Summary of dependent variables and property characteristics, MN

Variable	Description	Mean	Std. dev.	Min.	Med.	Max.
Sp	Sale price ($)	$274,027.53	$152,774.95	$5500.00	$240,000.00	$1,299,000.00
Lsp	log of sale price	12.38	0.56	8.61	12.39	14.08
Lsf	Living area (ft^2)	1956.58	978.6	155	1740.50	42,840.00
Acres	Land area (acres)	0.612	1.316	0.02	0.26	11.87
Age	Age of home at time of sale (years)	42.03	31.21	0	35	134
Agesq	Age of home at time of sale, squared ($years^2$)	2739.86	3587.53	0	1225.00	17,956.00
Salesqtr	Quarter of sale	2.31	0.82	1	2	4
Salesyr	Year of sale	2016	2	2010	2016	2020

Table A.7
Summary of dependent variables and property characteristics, NC

Variable	Description	Mean	Std. dev.	Min.	Med.	Max.
Sp	Sale price ($)	$233,970.66	$169,170.45	$5050.00	$194,000.00	$1,499,500.00
Lsp	log of sale price	12.12	0.75	8.53	12.18	14.22
Lsf	Living area (ft^2)	2091.02	1110.70	150	1852.00	120,215.00
Acres	Land area (acres)	0.788	1.437	0.021	0.36	14.14
Age	Age of home at time of sale (years)	29.48	24.08	0	22	114
Agesq	Age of home at time of sale, squared ($years^2$)	1448.56	2083.56	0	484	12,996.00
Salesqtr	Quarter of sale	2.26	0.86	1	2	4
Salesyr	Year of sale	2016	3	2004	2016	2020

Table A.8
Summary of dependent variables and property characteristics, NJ

Variable	Description	Mean	Std. dev.	Min.	Med.	Max.
Sp	Sale price ($)	$390,953.28	$243,373.52	$5143.00	$340,000.00	$1,599,999.00
Lsp	log of sale price	12.68	0.66	8.55	12.74	14.29
Lsf	Living area (ft^2)	1959.42	868.99	160	1786.00	19,176.00
Acres	Land area (acres)	0.393	0.656	0.006	0.185	6.167
Age	Age of home at time of sale (years)	56.92	30.02	0	57	139
Agesq	Age of home at time of sale, squared ($years^2$)	4140.35	3664.38	0	3249.00	19,321.00
Salesqtr	Quarter of sale	2.31	0.86	1	2	4
Salesyr	Year of sale	2014	4	2004	2014	2020

Table A.9
Categorical variables representing property characteristics (* = omitted category in regressions)

Variable	Category
Fullbaths	Number of full bathrooms missing*
	1 full bathroom
	2 full bathrooms
	3 full bathrooms
	4 full bathrooms
	$\geq$ 5 full bathrooms
Actype	Air conditioning code missing*
	Central AC
	AC type unknown
	Refrigeration AC
	Separate AC system
	No AC
	Evaporative AC
	All other types of AC
Constrtype	Construction type missing*
	Wood construction type
	Frame construction type
	Wood metal/frame construction type
	All other construction types
Heattype	Heating type missing*
	Central heat
	Forced air
	Unknown heating type
	Forced hot water

(*continued on next page*)

Table A.9 (*continued*)

Variable	Category
	Heat pump
	Hot air
	Floor/wall furnace
	No heat
	Steam
	All other heating types
Extwalltype	Exterior wall type missing*
	Stucco
	Frame
	Vinyl
	Aluminum/vinyl
	Wood siding/shingle
	Brick
	Aluminum siding
	Wood siding
	Wood
	All other wall codes
Fireplace	No fireplace indicated*
	Fireplace present
Garagecode	Garage type missing*
	Undefined garage type
	Attached
	Attached frame
	Undefined type – 2 car
	Detached
	Finished
	Basement
	Carport
	Undefined type – 1 car
	Frame
	Attached finished
	Attached garage/carport
	All other garage codes
Stories	Number of stories missing*
	0 to 1 stories
	1 to 2 stories
	2 to 3 stories
	>3 stories
View	View category missing*
	Average view
	All other view categories
newconstruction	New construction not indicated*
	New construction

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Exhibit 14

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LINEA ENERGY
RENEWABLES REENVISIONED

230 California Street, Suite 303
San Francisco CA 94111

July 19, 2024

Jordan Yutzy
Building and Development Manager
Santa Fe County
100 Catron St.
Santa Fe, NM 87501

RE: Pentstemon Solar and Globemallow Solar – TAC Meeting Request Letter of Intent

To Whom It May Concern:

Pentstemon and Globemallow are two planned, collocated solar projects with energy storage located off Route 41 near Stanley, NM. Based on our review of the Santa Fe Sustainable Development Code (the "Code"), the projects are considered commercial solar energy production facilities and other electrical generation facilities. They are located in the Agricultural/Ranching District and thus will require a Conditional Use Permit pursuant to Section 4.9.6 of the Code. We are submitting this letter of intent as a request to be placed on the agenda for TAC to commence the application process for the CUP. Please see below and attached for further details on the projects

Project Description	Pentstemon is a 199 MWac planned solar facility with 100 MW of planned energy storage, to be located on approximately 1,936 acres. Globemallow is a 150 MWac planned solar facility with 75 MW of planned energy storage, to be located on approximately 960 acres. The projects are located on contiguous land and will each interconnect to the Diamond Trail-Clines Corner 345kV transmission line that crosses the project land. The projects' improvements will include the installation of solar racking, modules, appurtenant electrical equipment, energy storage units, and a substation. The projects will also require ancillary improvements, including the improvement of an existing access road and the construction of an operations and maintenance building.
Project Location (Pentstemon)	35.202755, -105.93105935

Project Location (Globemallow)	35.191961, -105.929503
Pentstemon Parcel #'s	910005752, 910005753, 910005736, 910005737, 910005738, 910005739, 910005740, 910005741, 910005742, 910005743, 910005745, 910005746, 910005747, 910005748, 910005749, 910005750, 910005751, 910010647, 910014134, 910014135
Globemallow Parcel #s	99309472, 94448768
Project Site Maps	Attached
Property Address	16-26 Via Compostela, Stanley, NM 87056
Proposed Entrance Points	Linea Energy proposes that the access road for the projects to be on Via Compostela Road. There is an existing road that will need minor upgrades to be suitable for traffic during construction. This road is on the Pentstemon property and will be extended to reach Globemallow.
Completed Due Diligence	Critical Issues Analysis, Hydrology Study, Wetland Delineation, Phase 1 Environmental Site Assessment, Fatal Flaw Analysis, and a Biological Resources Report
In-Progress Due Diligence	ALTA and TOPO Survey, and Cultural Resources Survey and Correspondence with SHPO
Project Contacts	**Andrew Davidson** Associate, West Development Email: Andrew.davidson@lineaenergy.com Cell: (760) 579-8719 **Heather Kane** Director, M&A & Development Operations Email: heather.kane@lineaenergy.com **Jonathan Vasdekas** Executive Vice President, Development Email: Jonathan.Vasdekas@lineaenergy.com
Notarized Letters of Consent for land use approvals from the landowner	A notarized letter of consent has been received from one landowner to proceed with land use approvals. The second letter of consent is in progress.

We look forward to discussing the projects further.

Sincerely,

Andrew Davidson

Attachments

- Pentstemon Conceptual Site Plan Version A
- Pentstemon Conceptual Site Plan Version B
- Globemallow Conceptual Site Plan
- Globemallow and Pentstemon combined conceptual site plan

Exhibit 15

Ohio Supreme Court ruling paves way for utility regulator appeals

Ruling sets stage for what consumers' group hopes will be eventual refunds

By Thomas Gnau Dayton Daily News
Nov 27, 2024

On Tuesday, the Ohio Supreme Court rejected AES Ohio's bid to end appeals by a consumers group that, if successful, could one day result in millions in consumer refunds. The ruling sets the stage for the Supreme Court to hear appeals from the Office of the Ohio Consumers' Counsel (OCC) that office leaders think might eventually result in ratepayer refunds.

Earlier this year, Dayton electric utility AES Ohio asked the court to dismiss appeals in the case from the OCC, which seeks to represent consumers in matters involving utilities. The court in August rejected an earlier motion to dismiss from the utility.

The case stretches back to 2021, when the Ohio utility regulator PUCO ordered AES Ohio to include language in a tariff making a rate stabilization charge "refundable 'to the extent permitted by law.'"
AES Ohio objected that such refund language had not been a "provision, term or condition" of AES Ohio's earlier electric security plan or operating plan.

The OCC disagreed, filing its own brief in the case, arguing that "since Dec. 19, 2019, Dayton-area consumers have been paying ... unreasonable rates to (AES Ohio) for electric service that include charges for so-called stability, which this court has consistently struck down."

Matt Schilling, a spokesman for the PUCO, said in September only the Supreme Court can decide if the stability charges should be refundable. The PUCO did order AES Ohio to include the refund language in its tariff, Schilling noted. And AES Ohio abided by that order, he said. "I am pleased with the outcome today and appreciate the clarity provided by the Supreme Court of Ohio," PUCO Chair Jenifer French said Tuesday.

"AES Ohio appreciates that today the Ohio Supreme Court clarified a procedural issue created by its decision earlier this year in a separate Moraine Wind case," AES Ohio said in a statement to the Dayton Daily News. "However, the court decision today did not address the merits of Ohio Consumers' Counsel appeals in our case. AES Ohio believes that the OCC appeals are without merit and will continue to oppose them."

To set the stage for eventual refunds, three things need to happen, the OCC has said. This ruling was a first step, in the view of the consumers' group.

Exhibit 16

New Mexicans for Responsible Renewable Energy

What is UL9540A
What is it's significance in this project

Other causes of failures, fires and threats

Is thermal runaway a question of old age

Property values

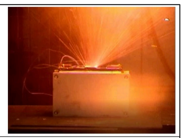
Better alternative

UL 9540A test has 4 levels

- Cell: can a cell be forced into thermal runaway
- Module: will the heat/fire infect another cell or expand outside the module
- Unit: will the heat/fire infect another unit
- Installation: include the use of fire mitigation equipment

Requirement	Result **Cell** Test	Verdict
a) Thermal runaway cannot be induced in the cell and	Thermal runaway was achieved in all five cells	F
b) The cell vent does not present a flammable hazard	Cell vent found to be flammable	F

Cell 1 - Immediately before thermal runaway* (00:43:54)



Cell 1 - Thermal runaway (00:43:55)

Cell 1 - After the end of test

Requirement	Result **Module** Test	Verdict
a) Thermal runaway is contained	A single cell infected the majority of the cells	F
b) The cell vent is not flammable	Cell vent found to be flammable	F

Other Observations During Module Test
Flying debris Explosive discharge of gas Sparks or electric arcs

(c) Thermal Runaway (Initiating Cell)
00:46:14

(d) First Flame
00:46:15

(e) Continuation of Initiating Cell Thermal Runaway
00:46:18

(f) Continued Flaming (post initiating cell thermal runaway)
00:46:41

(g) First propagation after Initiating Cell (Cell 35)
00:58:04

(h) Second propagation After Initiating Cell (Cell 31)
1:13:49

Requirement	Result **Unit** Test	Verdict
a) Flaming outside the BESS is not observed	Flaming outside the BESS was observed	F
b) Surface temperatures on walls do not exceed 97˚C	Maximum surface temperature was 169˚C	F
c) Heat flux on the center did not exceed $1.3 kW/m^2$	Heat flux measured $6.74 kWm^2$	F

Other Observations During Unit Test
Flaming outside of unit Explosive discharge of gas Gas analysis: 3340.26 L of total hydrocarbons 343.97 L of carbon monoxide

Post Test Observations
Thermal runaway behaviour during disposal

Necessity for an Installation level test
[X] The performance criteria of the unit level test as indicated in Table 9.1 of UL 9540A 4th edition has not been met, therefore an installation level testing in accordance with UL 9540A will need to be conducted on the representative the installation with this unit installed. **[ ]** The performance criteria of the unit level tests as indicated in Table 9.1 of UL 9540A 4th edition has been met, therefore an installation level testing in accordance with UL 9540A need not be conducted.

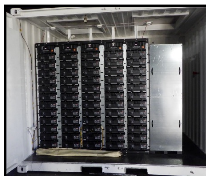


Figure 1 – Picture of the units in the container

(c) Initiating Unit Thermal Runaway [00:42:25]

Figure 2 – Picture of the container

(d) Ignition [00:42:30]

Installation level test

- UL: "container becomes the test room, to understand the hazards associated with container BESS design, without resulting in the testing hazards associated with trying to run the test on a completely populated container BESS"
- The installation testing was done indoors

If outdoors:

- Wind speed ≤ 12 mph
- Control of vegetation and combustibles in the test area

Installation Test Results

No spreading of thermal runaway
No flaming or flying debris outside the enclosure
Maximum enclosure wall surface temperature was 670˚C

Maximum enclosure wall surface temperature was 670˚C

In BESS unit with combustible materials wall surfaces need to be ≤ 97˚C + ambient = 120˚C (dangers of inducing TR or burns)

AES: "containers are rated non-combustible"

The container door material was metal, therefore, it is non-combustible.	N/A

"Surface temperatures are not applicable
if wall assemblies, cables, wiring and other combustible materials are not present

If they are not present, the report shall note that the installation shall contain no combustible materials"

We have to depend on fire suppression and explosion protection

- The system including the direct injection system and the container were not certified
- There was an error in recording located inside of container, some snapshots of video were not available: recorded last snap shot was at 00:55:00 test ended at 02:19:57
- The hydrogen measurement system malfunctioned during the test
- Testing to determine fire characterization was done at battery system level rather than a complete BESS
- UL did not select the samples, determine whether the samples were representative of production samples, witness the production of the test samples, was not provided with information relative to the identification of the component materials used in the samples
- The test results relate only to the samples tested

Problems with fire suppression system per Atar fire review

- Provide documentation this system complies with requirements for a fire suppression system
- It cannot be determined if the system is for suppression or for thermal runaway propagation prevention. If this is not a fire suppression system, specifically invoke approval for omission of a fire suppression system
- If the NOVEC 1230 system is a thermal runaway propagation prevention system provide a separate report interpreting the test results, defining the applicable codes and standards and validating the use and limitations
- The direct Injection System is credited as a preventative barrier. Determine if this is a mitigate or preventative barrier. Revise or confirm as appropriate
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Despite these results, the installation demonstrated compliance with the standards because:

- Fires, flaming combustion, flying debris, explosive discharge of gas and sparks and electric arcs will not prevent occupants form evacuating to a safe location
- A ventilation system will release explosive gasses so that structural and mechanical damage is minimized

Major analysis assumptions and limitations

- Major BESS failures not yet known by industry may exist

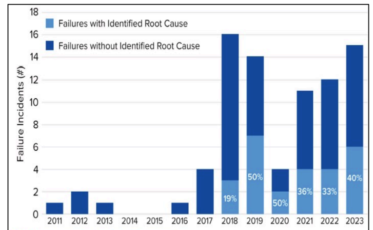

Figure 3. BESS Failures with Identified Root Cause Over Time

- Failures in more than one enclosures are not considered

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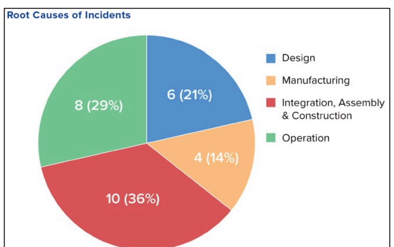

Figure 4. Breakdown of BESS Failures by Root Cause

- Protection systems inside the BESS enclosure and site wide must be installed per regulatory requirements. This has not been verified

Other causes of fires and failures

Cell failure test method performed for the module level (summary of method and test clause):
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☐ Nail Penetration ☐ Overcharge
☐ External short circuit (*X Ω external resistance*)
☐ Others

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2017	**Tubbs**	**5,636**	2020	Glass	1,520
2025	Palisades (under investigation)	5,316	2020	LNU Lightning Complex	1,491
2025	Eaton (under investigation)	>5,000	2020	CZU Lightning Complex	1,490
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2018	**Woolsey**	**1,643**	1999	Jones	954

Source: CalFire · By The New York Times

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"As a test method, UL 9540A testing does not provide a certification or pass/fail results," said Maurice Johnson, business development engineer with UL's Energy Systems and e-Mobility group. "The best way for manufacturers to share that their energy storage battery products have been tested for thermal runaway is to list them in the UL 9540A test database."

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Today's standards are reluctant to prescribe that a battery module shall not cascade from cell to cell
Standards are intentionally technology-agnostic and should not impose restriction on an industry that could increase cost

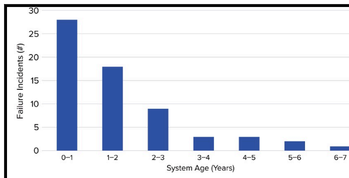
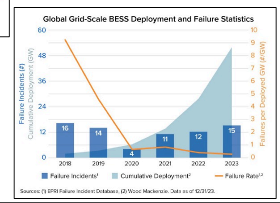


Figure 5. BESS Age at Failure, where known

Electric Power Research Institute EPRI



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EPRI data

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Location	Age at incident
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Moss Landing	0.8
Moss Landing	1
Moss Landing	4
Escondido	7.6
San Diego	3.7
Idaho Melba	Pre-commission
Valley Center	0.2 and 1.6
NY, Warwick	0.1 and 0.1
NY, East Hampton	4.8
Rio Dell	4
AZ Chandler	3
AZ Surprise	2.1

200.000 Panels

- Fires start at cables and connectors going into the panels, and the external electrical cabinets and inverters
- Electrical shorts, flying sparks, heat buildup inside. "Avian incident" in California 2019 fire
- Risks are underestimated and underreported
- 430 cases 50% was in the panels themselves
- 25% were serious fires, difficult to extinguish and spread beyond the area
- Continue generate DC current, which is more unpredictable and difficult to protect than AC power (fire fighter safety)
- Environmental pollution due to the toxic smoke and toxic materials in the panels, could leak and contaminate the groundwater, serious impact on biodiversity

Solar farm fire in California destroys 1,127 acres

The United States doesn't centrally track solar panel fires – with the National Fire Data Center classifying them in the "other" category.

Aerial footage of the blaze at Finley Solar Farm

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Hearing Officer
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The criteria that typically correlates with downward adjustments on property values such as noise, odor, and traffic all indicate that a solar farm is a compatible use for rural and suburban residential transition areas and that it would function in a harmonious manner with this area.

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This 200 MW battery storage system is located on a parcel with significant adjacency to industrial uses and residential uses. For these reasons it would be difficult to measure impacts due to the other adjoining industrial uses that might also have an impact. Given that most of the adjoining uses are industrial, I have not dug further on this one.

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Shedding light on large-scale solar impacts: An analysis of property values and proximity to photovoltaics across six U.S. states

Salma Elmallah [a,*], Ben Hoen [a], K. Sydny Fujita [a], Dana Robson [a], Eric Brunner [b]

[a] Energy Analysis and Environmental Impacts Division, Lawrence Berkeley National Lab, 1 Cyclotron Road, Berkeley, CA, 94720, USA
[b] Department of Public Policy, University of Connecticut, 10 Prospect Street, Hartford, CT, 06103, USA

- Lawrence Berkeley National Laboratory looked at residential home prices in six states that together account for over 50% of the installed capacity of large-scale in the United States
- The study is the largest so far looking at how solar installations affect property values
- The researchers found the area where a solar installation is built has an enormous impact on whether it affects nearby home prices
- Homes in rural and agricultural areas saw declines in home prices, especially where solar farms were replacing agricultural land uses, as opposed to urban or suburban installations which saw no change in home prices
- The projects also tended to be medium-sized, most fewer than 35 acres. Large solar installations tend not to be built near areas where there are nearby homes that sold
- For homes within 0.5 miles of a large-scale solar project compared to 2-4 miles away they found a reduction in home sale prices in MN (4%) in NC (5.8%) and NJ (5.6%)
- Large-scale solar project developed on previously agricultural land, near homes in rural areas and extremely large solar project were found to be linked to adverse home sale price impacts within 0.5 mile

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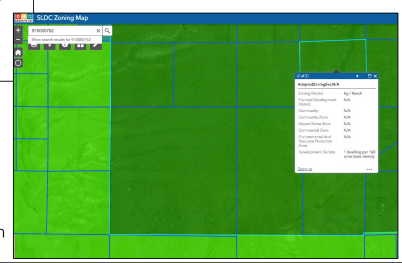
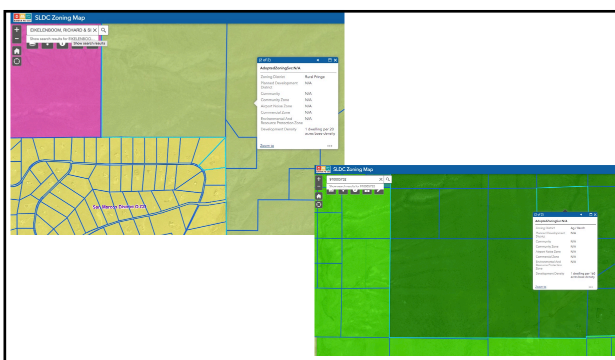
3 times as large
Gen-tie line 0.1 mile
No update to connect to the grid
Zoning allowed

AES 2.3 mile
Upgrade transmission station





Conclusions

- Promises of safety through testing and standards are empty
- The systems components performed badly
- The back up systems are not certified, documentation is incomplete and showed malfunction
- Other threats are not addressed
- The 200.000 panels are not considered
- The property values will decline
- There is a better alternative

Quotes

NM State Representative Matthew McQueen
“We have asked for a bill to be drafted that would direct the Public Regulation Commission to prepare rules dealing with appropriate siting of battery installation, solar installation and transmission lines”

San Diego County Commissioner: “I would not want them on my block”. “Don’t put them anywhere were people live”

Professor of chemical engineering at Texas University: “Some improvements, such as fire prevention measures, can be made to reduce fire risk with lithium batteries, but the only way to really address the problem is safer technology”

Professor Ezekoye of mechanical engineering at Texas University : A battery protection system in fine, but if you have significant enough failure event, it will be incapable of dealing with these severe environmental issues”

"It keeps me focussed."

Exhibit 17

Exhibit list New Mexicans for Responsible Renewable Energy

Planning Commission meeting on February 3, 2025

Exhibit 1: Preliminary Hazard Mitigation Analysis
Exhibit 2: Atar fire Review.
Exhibit 3: Example better UL9540A test
Exhibit 4: Insights from EPRIs Battery Energy Storage Systems BESS Failure Incident Database Analysis of Failure Root Cause
Exhibit 5: More than a quarter of energy storage systems have fire detection and suppression defects report Utility Dive
Exhibit 6: What Causes California Fires Power Lines Can Be a Contributor
Exhibit 7: Solar panels fires
Exhibit 8: How Solar Farm Fires Can Damage the Environment
Exhibit 9: Firetrace-Report-Hidden-Danger-Solar-Farms
Exhibit 10: Hearing Officer Recommended Order
Exhibit 11: Kirkland Appraisal Study
Exhibit 12: Do solar farms hurt property values USA today
Exhibit 13: Shedding light on large scale solar
Exhibit 14: Linea Letter of Intent (Santa Fe County)
Exhibit 15: Ohio Supreme Court ruling paves way for utility regulator appeals
Exhibit 16: Presentation Planning Commission
Exhibit 17: Exhibit list New Mexicans for Responsible Renewable Energy

I have no witnesses, but I would like to question Nicolas Bartlett or Todd La Berge from Atar Fire.

New Mexicans for Responsible Renewable Energy

What is UL9540A
What is it’s significance in this project

Other causes of failures, fires and threats

Is thermal runaway a question of old age

Property values

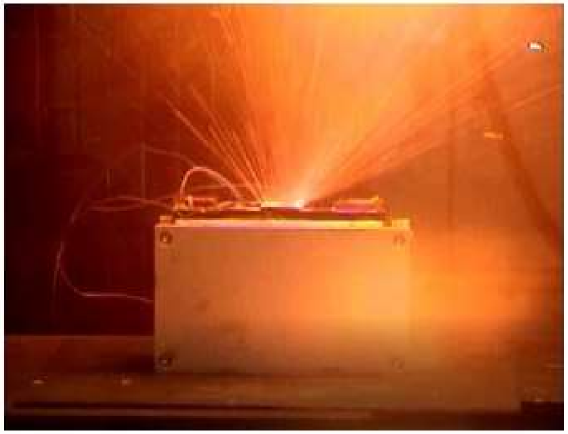
Better alternative

UL 9540A test has 4 levels

- Cell: can a cell be forced into thermal runaway
- Module: will the heat/fire infect another cell or expand outside the module
- Unit: will the heat/fire infect another unit
- Installation: include the use of fire mitigation equipment

Requirement	Result **Cell** Test	Verdict
a) Thermal runaway cannot be induced in the cell and	Thermal runaway was achieved in all five cells	F
b) The cell vent does not present a flammable hazard	Cell vent found to be flammable	F

Cell 1 - Immediately before thermal runaway* (00:43:54)



Cell 1 - Thermal runaway (00:43:55)

Cell 1 - After the end of test

Requirement	Result **Module** Test	Verdict
a) Thermal runaway is contained	A single cell infected the majority of the cells	F
b) The cell vent is not flammable	Cell vent found to be flammable	F

Other Observations During Module Test
Flying debris Explosive discharge of gas Sparks or electric arcs

(c) Thermal Runaway (Initiating Cell)
00:46:14

(d) First Flame
00:46:15

(e) Continuation of Initiating Cell Thermal Runaway
00:46:18

(f) Continued Flaming (post initiating cell thermal runaway)
00:46:41

(g) First propagation after Initiating Cell (Cell 35)
00:58:04

(h) Second propagation After Initiating Cell (Cell 31)
1:13:49

Requirement	Result **Unit** Test	Verdict
a) Flaming outside the BESS is not observed	Flaming outside the BESS was observed	F
b) Surface temperatures on walls do not exceed 97˚C	Maximum surface temperature was 169˚C	F
c) Heat flux on the center did not exceed 1.3kW/m^2	Heat flux measured 6.74kWm^2	F

Other Observations During Unit Test
Flaming outside of unit Explosive discharge of gas Gas analysis: 3340.26 L of total hydrocarbons 343.97 L of carbon monoxide

Post Test Observations
Thermal runaway behaviour during disposal

Necessity for an Installation level test
[X] The performance criteria of the unit level test as indicated in Table 9.1 of UL 9540A 4th edition has not been met, therefore an installation level testing in accordance with UL 9540A will need to be conducted on the representative the installation with this unit installed. [ ] The performance criteria of the unit level tests as indicated in Table 9.1 of UL 9540A 4th edition has been met, therefore an installation level testing in accordance with UL 9540A need not be conducted.

Figure 1 – Picture of the units in the container

Figure 2 – Picture of the container

(c) Initiating Unit Thermal Runaway
[00:42:25]

(d) Ignition
[00:42:30]

Installation level test

- UL: "container becomes the test room, to understand the hazards associated with container BESS design, without resulting in the testing hazards associated with trying to run the test on a completely populated container BESS"
- The installation testing was done indoors

If outdoors:

- Wind speed ≤ 12 mph
- Control of vegetation and combustibles in the test area

Installation Test Results
No spreading of thermal runaway No flaming or flying debris outside the enclosure Maximum enclosure wall surface temperature was 670°C

Maximum enclosure wall surface temperature was 670˚C

In BESS unit with combustible materials wall surfaces need to be ≤ 97˚C + ambient = 120˚C (dangers of inducing TR or burns)

AES: "containers are rated non-combustible"

The container door material was metal, therefore, it is non-combustible.	N/A

"Surface temperatures are not applicable
if wall assemblies, cables, wiring and other combustible materials are not present

If they are not present, the report shall note that the installation shall contain no combustible materials"

We have to depend on fire suppression and explosion protection

- The system including the direct injection system and the container were not certified
- There was an error in recording located inside of container, some snapshots of video were not available: recorded last snap shot was at 00:55:00 test ended at 02:19:57
- The hydrogen measurement system malfunctioned during the test
- Testing to determine fire characterization was done at battery system level rather than a complete BESS
- UL did not select the samples, determine whether the samples were representative of production samples, witness the production of the test samples, was not provided with information relative to the identification of the component materials used in the samples
- The test results relate only to the samples tested

Problems with fire suppression system per Atar fire review

- Provide documentation this system complies with requirements for a fire suppression system
- It cannot be determined if the system is for suppression or for thermal runaway propagation prevention. If this is not a fire suppression system, specifically invoke approval for omission of a fire suppression system
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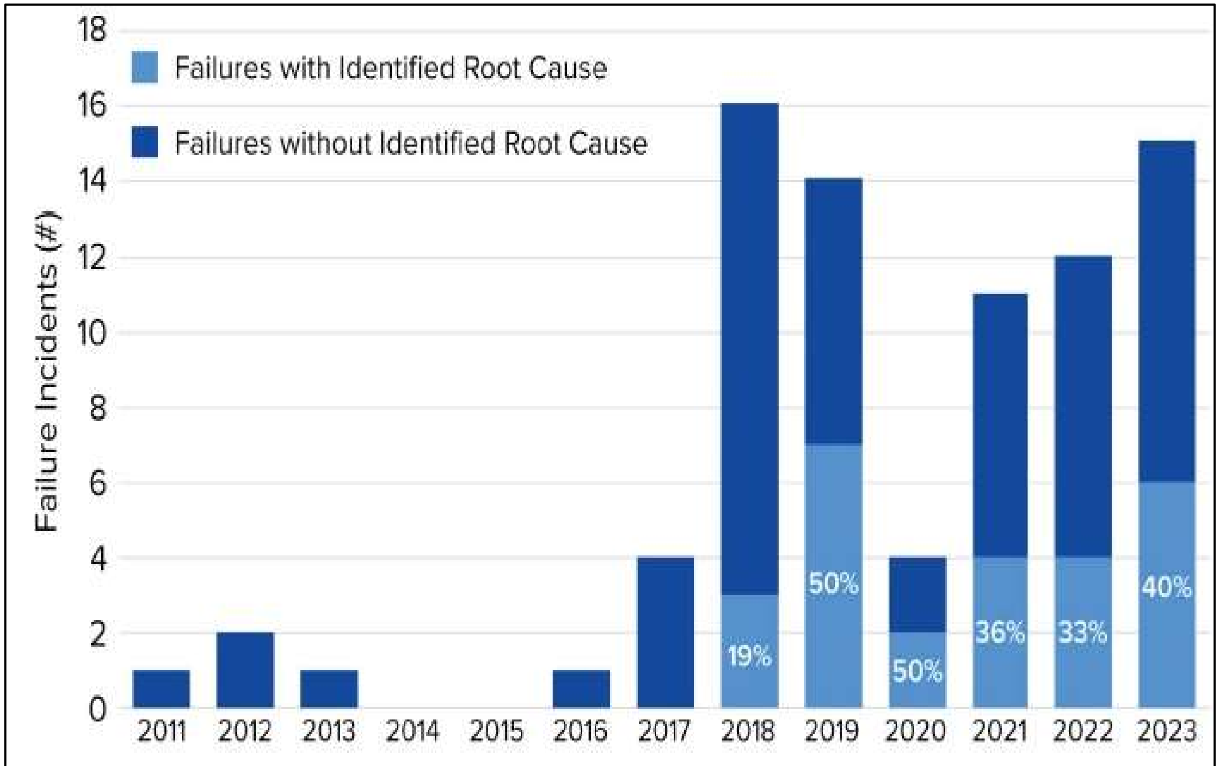

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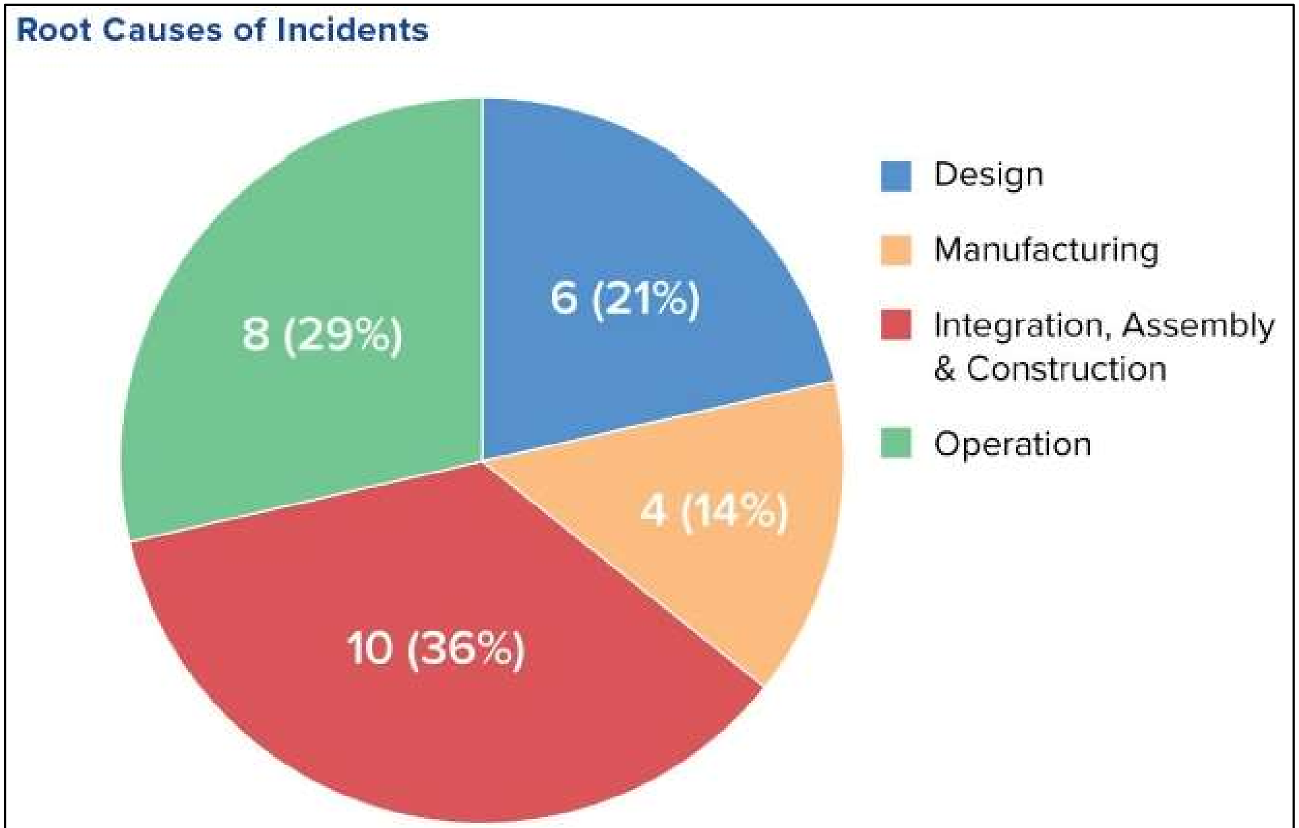

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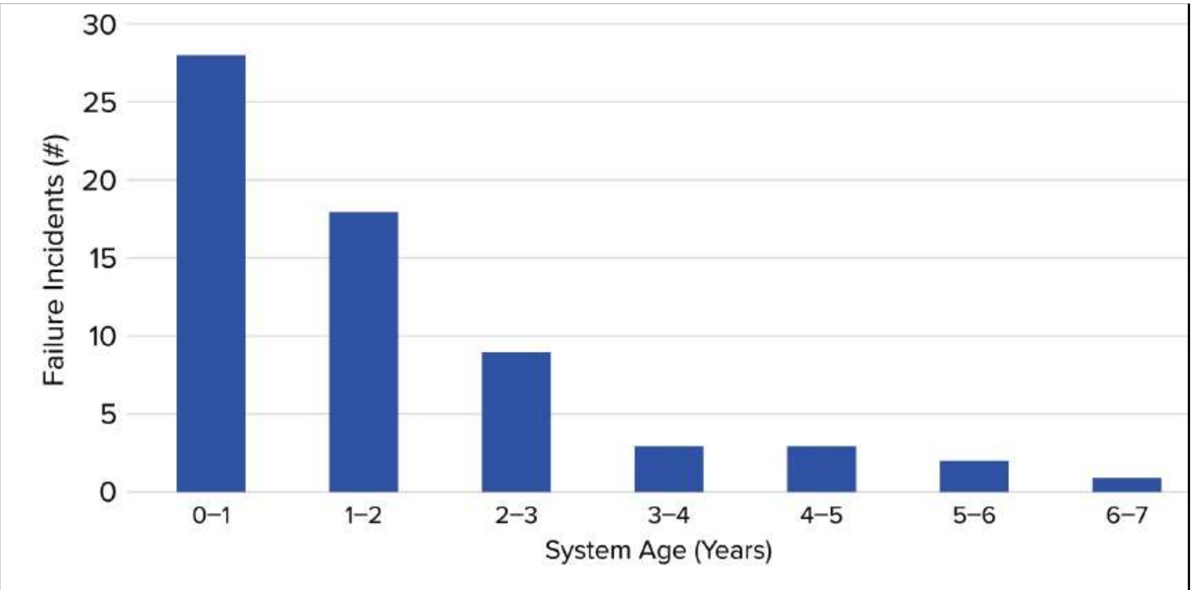

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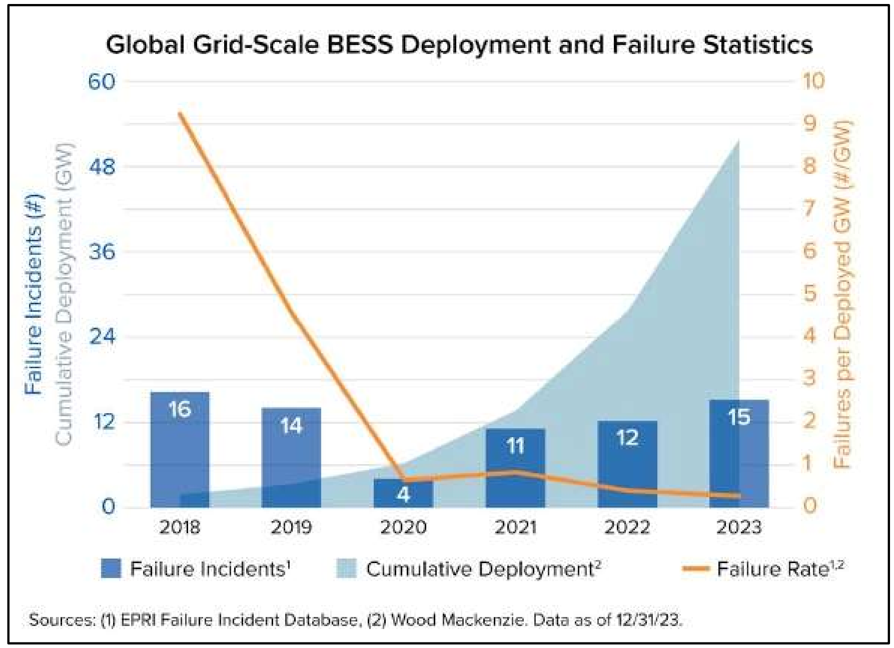

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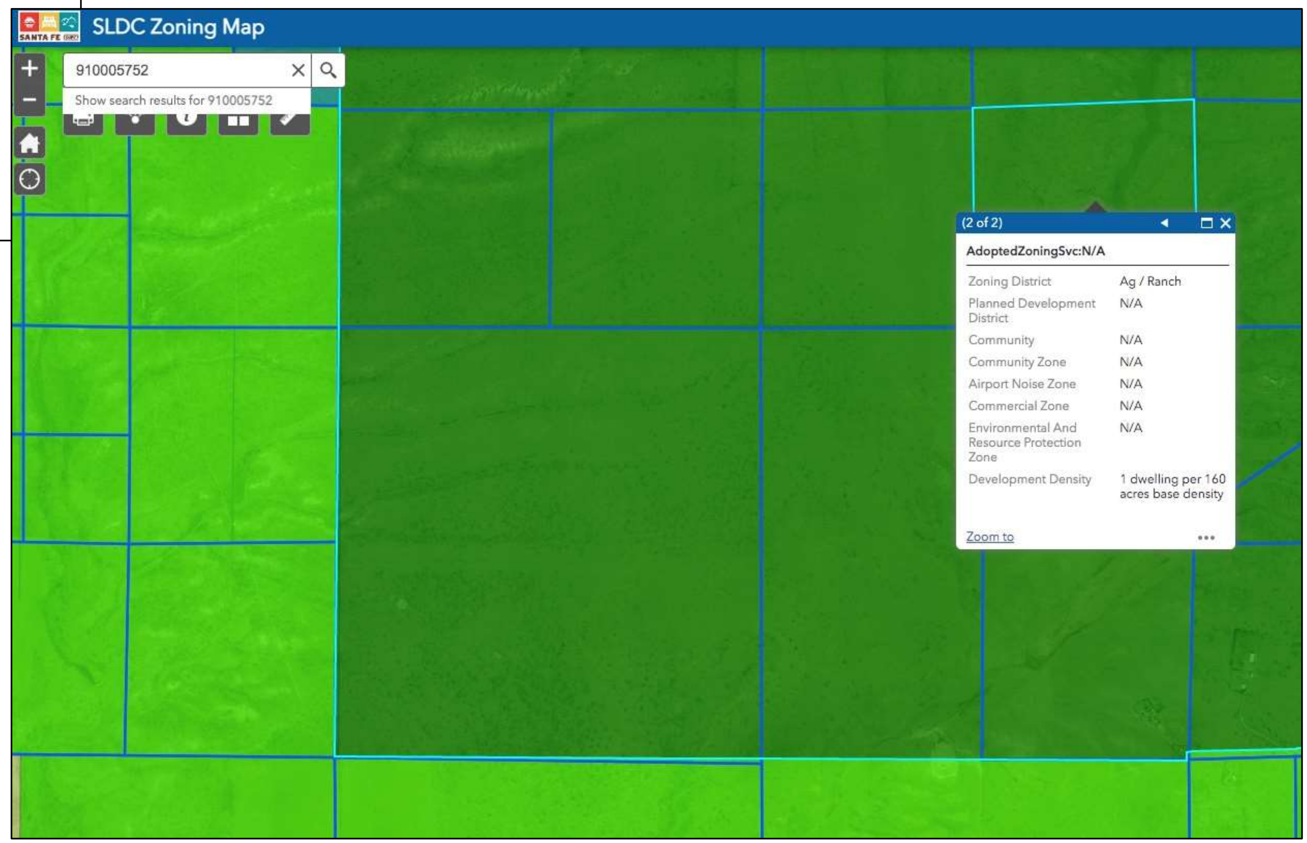
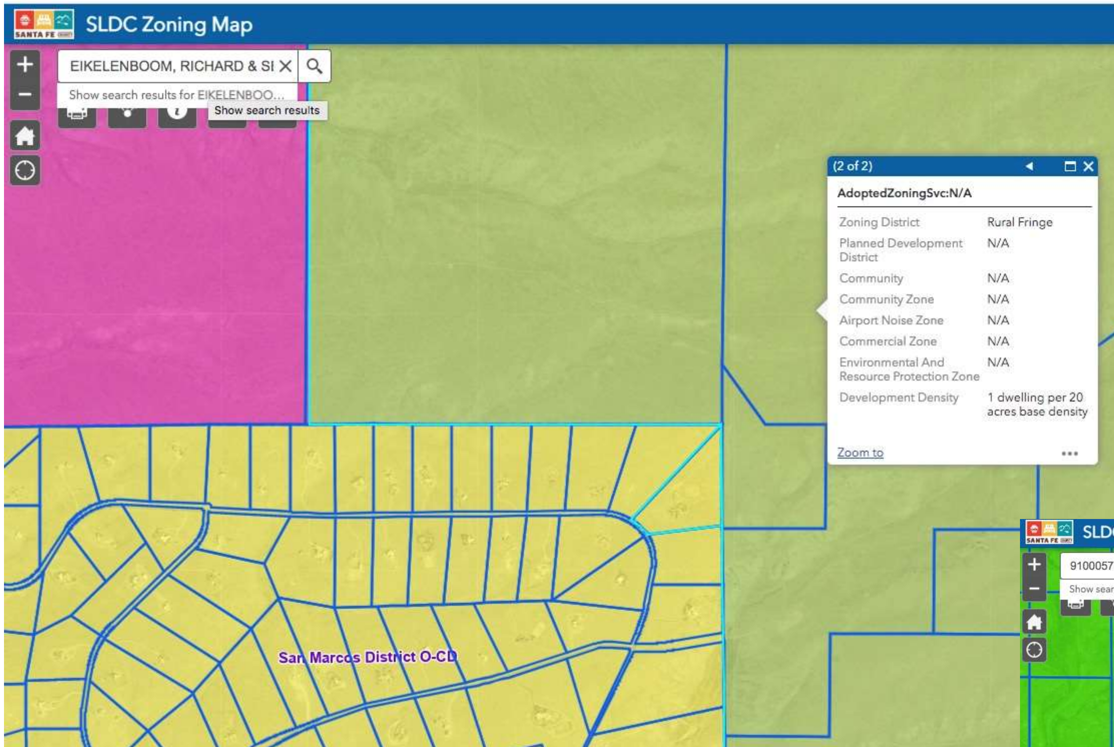
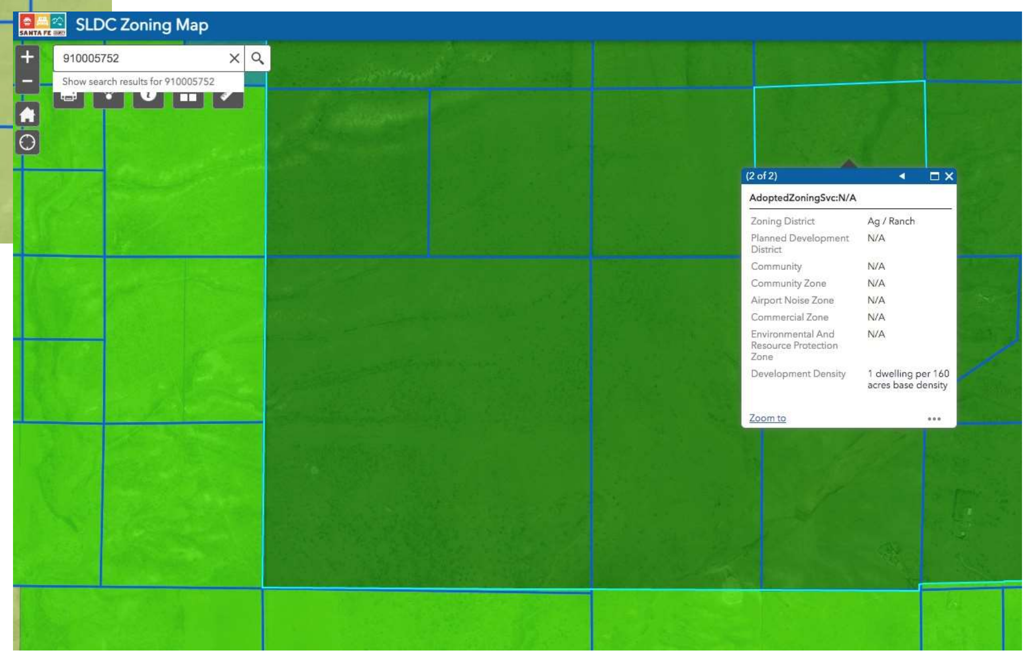



SLDC Zoning Map
EIKELENBOOM, RICHARD & SI
Show search results for EIKELENBOO...
Show search results
(2 of 2)
AdoptedZoningSvc:N/A
Zoning District Rural Fringe
Planned Development District N/A
Community N/A
Community Zone N/A
Airport Noise Zone N/A
Commercial Zone N/A
Environmental And Resource Protection Zone N/A
Development Density 1 dwelling per 20 acres base density
Zoom to
San Marcos District O-CD


SLDC Zoning Map
910005752
Show search results for 910005752
(2 of 2)
AdoptedZoningSvc:N/A
Zoning District Ag / Ranch
Planned Development District N/A
Community N/A
Community Zone N/A
Airport Noise Zone N/A
Commercial Zone N/A
Environmental And Resource Protection Zone N/A
Development Density 1 dwelling per 160 acres base density
Zoom to

Conclusions

- Promises of safety through testing and standards are empty
- The systems components performed badly
- The back up systems are not certified, documentation is incomplete and showed malfunction
- Other threats are not addressed
- The 200.000 panels are not considered
- The property values will decline
- There is a better alternative

Quotes

NM State Representative Matthew McQueen
“We have asked for a bill to be drafted that would direct the Public Regulation Commission to prepare rules dealing with appropriate siting of battery installation, solar installation and transmission lines”

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"It keeps me focussed."

New Mexicans for Responsible Renewable Energy

What is UL9540A
What is it’s significance in this project

Other causes of failures, fires and threats

Is thermal runaway a question of old age

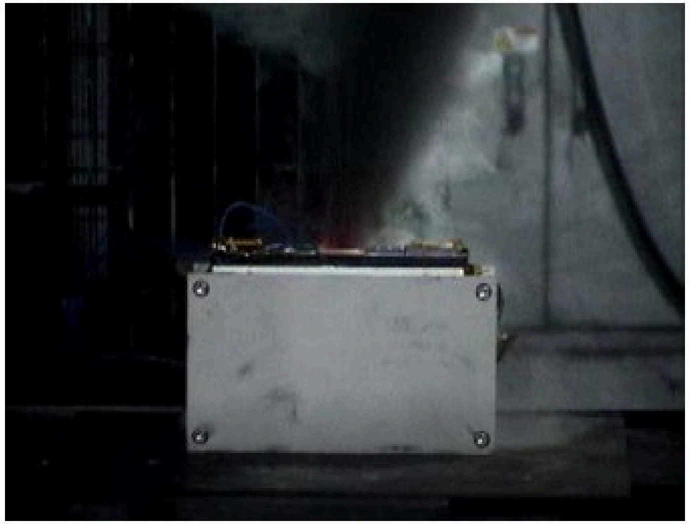
Property values

Better alternative

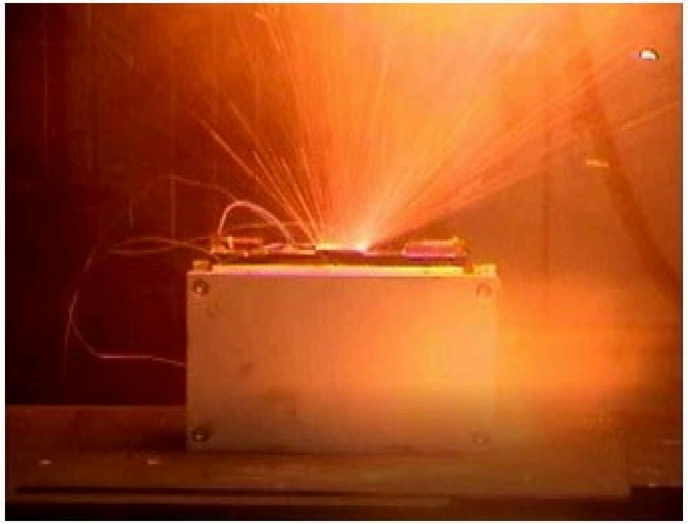
UL 9540A test has 4 levels

- Cell: can a cell be forced into thermal runaway
- Module: will the heat/fire infect another cell or expand outside the module
- Unit: will the heat/fire infect another unit
- Installation: include the use of fire mitigation equipment

Requirement	Result **Cell** Test	Verdict
a) Thermal runaway cannot be induced in the cell and	Thermal runaway was achieved in all five cells	F
b) The cell vent does not present a flammable hazard	Cell vent found to be flammable	F



Cell 1 - Immediately before thermal runaway* (00:43:54)



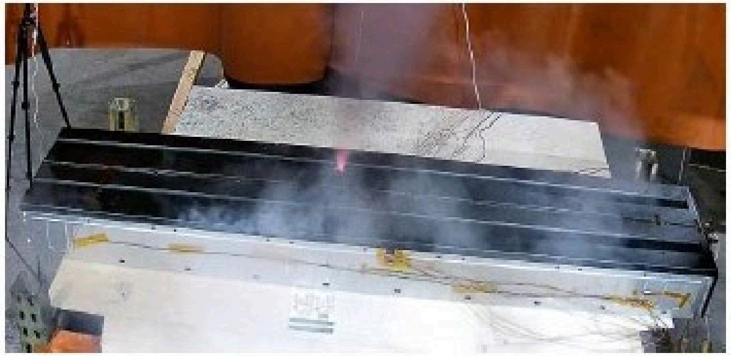
Cell 1 - Thermal runaway (00:43:55)

Cell 1 - After the end of test

Requirement	Result **Module** Test	Verdict
a) Thermal runaway is contained	A single cell infected the majority of the cells	F
b) The cell vent is not flammable	Cell vent found to be flammable	F

Other Observations During Module Test
Flying debris Explosive discharge of gas Sparks or electric arcs

(c) Thermal Runaway (Initiating Cell)
00:46:14



(d) First Flame
00:46:15

(e) Continuation of Initiating Cell Thermal Runaway
00:46:18

(f) Continued Flaming (post initiating cell thermal runaway)
00:46:41

(g) First propagation after Initiating Cell (Cell 35)
00:58:04

(h) Second propagation After Initiating Cell (Cell 31)
1:13:49

Requirement	Result **Unit** Test	Verdict
a) Flaming outside the BESS is not observed	Flaming outside the BESS was observed	F
b) Surface temperatures on walls do not exceed 97˚C	Maximum surface temperature was 169˚C	F
c) Heat flux on the center did not exceed 1.3kW/m^2	Heat flux measured 6.74kWm^2	F

Other Observations During Unit Test
Flaming outside of unit Explosive discharge of gas Gas analysis: 3340.26 L of total hydrocarbons 343.97 L of carbon monoxide

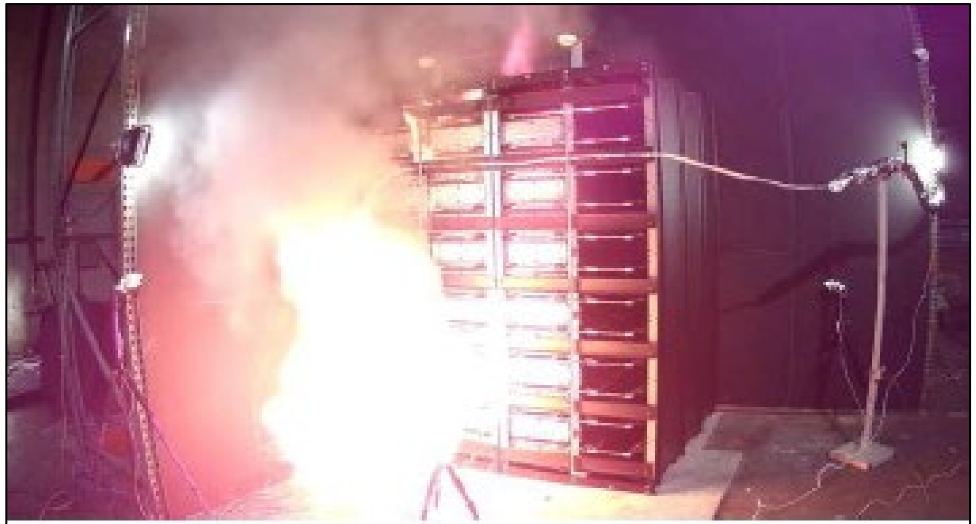
Post Test Observations
Thermal runaway behaviour during disposal

Necessity for an Installation level test
[X] The performance criteria of the unit level test as indicated in Table 9.1 of UL 9540A 4th edition has not been met, therefore an installation level testing in accordance with UL 9540A will need to be conducted on the representative the installation with this unit installed. **[ ]** The performance criteria of the unit level tests as indicated in Table 9.1 of UL 9540A 4th edition has been met, therefore an installation level testing in accordance with UL 9540A need not be conducted.

Figure 1 – Picture of the units in the container

(c) Initiating Unit Thermal Runaway
[00:42:25]

Figure 2 – Picture of the container



(d) Ignition
[00:42:30]

Installation level test

- UL: “container becomes the test room, to understand the hazards associated with container BESS design, without resulting in the testing hazards associated with trying to run the test on a completely populated container BESS”
- The installation testing was done indoors

If outdoors:

  - Wind speed ≤ 12 mph
  - Control of vegetation and combustibles in the test area

Installation Test Results
No spreading of thermal runaway No flaming or flying debris outside the enclosure Maximum enclosure wall surface temperature was 670˚C

Maximum enclosure wall surface temperature was 670˚C

In BESS unit with combustible materials wall surfaces need to be ≤ 97˚C + ambient = 120˚C (dangers of inducing TR or burns)

AES: "containers are rated non-combustible"

The container door material was metal, therefore, it is non-combustible.	N/A

"Surface temperatures are not applicable
if wall assemblies, cables, wiring and other combustible materials are not present

If they are not present, the report shall note that the installation shall contain no combustible materials"

We have to depend on fire suppression and explosion protection

- The system including the direct injection system and the container were not certified
- There was an error in recording located inside of container, some snapshots of video were not available: recorded last snap shot was at 00:55:00 test ended at 02:19:57
- The hydrogen measurement system malfunctioned during the test
- Testing to determine fire characterization was done at battery system level rather than a complete BESS
- UL did not select the samples, determine whether the samples were representative of production samples, witness the production of the test samples, was not provided with information relative to the identification of the component materials used in the samples
- The test results relate only to the samples tested

Problems with fire suppression system per Atar fire review

- Provide documentation this system complies with requirements for a fire suppression system
- It cannot be determined if the system is for suppression or for thermal runaway propagation prevention. If this is not a fire suppression system, specifically invoke approval for omission of a fire suppression system
- If the NOVEC 1230 system is a thermal runaway propagation prevention system provide a separate report interpreting the test results, defining the applicable codes and standards and validating the use and limitations
- The direct Injection System is credited as a preventative barrier. Determine if this is a mitigate or preventative barrier. Revise or confirm as appropriate
- HMA: “other key preventative barriers that may be present or in varying strength depending upon the final installation include system shut down capability, facility design and siting, emergency planning and fire service response”. Comments Atar: The HMA must reflect this specific installation and dictate all required parameters. Revise and clarify

Problems with fire suppression system per Atar fire review

- The direct injection system activates on smoke, it will do nothing to increase the amount of time for event detection. Please update
- HMA: “the strength of the gas detection system and direct injection is conditional based on the quality of the emergency response plan”. Atar: Clarify or remove
- Confirm if container based NOVEC is provided or if it is direct injection thermal runaway propagation system. The ERP and HMA contain conflicting information
- Additional information is required about the NOVEC system. Clearly define the suppression system and associated hazards in the ERP
- Confirm AES capabilities for air monitoring during a large-scale incident to inform need for public protective measures
- The HMA should discuss the NOVEC system, because this system is not an NFPA 2001 system per the NFPA 855, it cannot be called a fire suppression system

Despite these results, the installation demonstrated compliance with the standards because:

- Fires, flaming combustion, flying debris, explosive discharge of gas and sparks and electric arcs will not prevent occupants form evacuating to a safe location

- A ventilation system will release explosive gasses so that structural and mechanical damage is minimized

Major analysis assumptions and limitations

- Major BESS failures not yet known by industry may exist

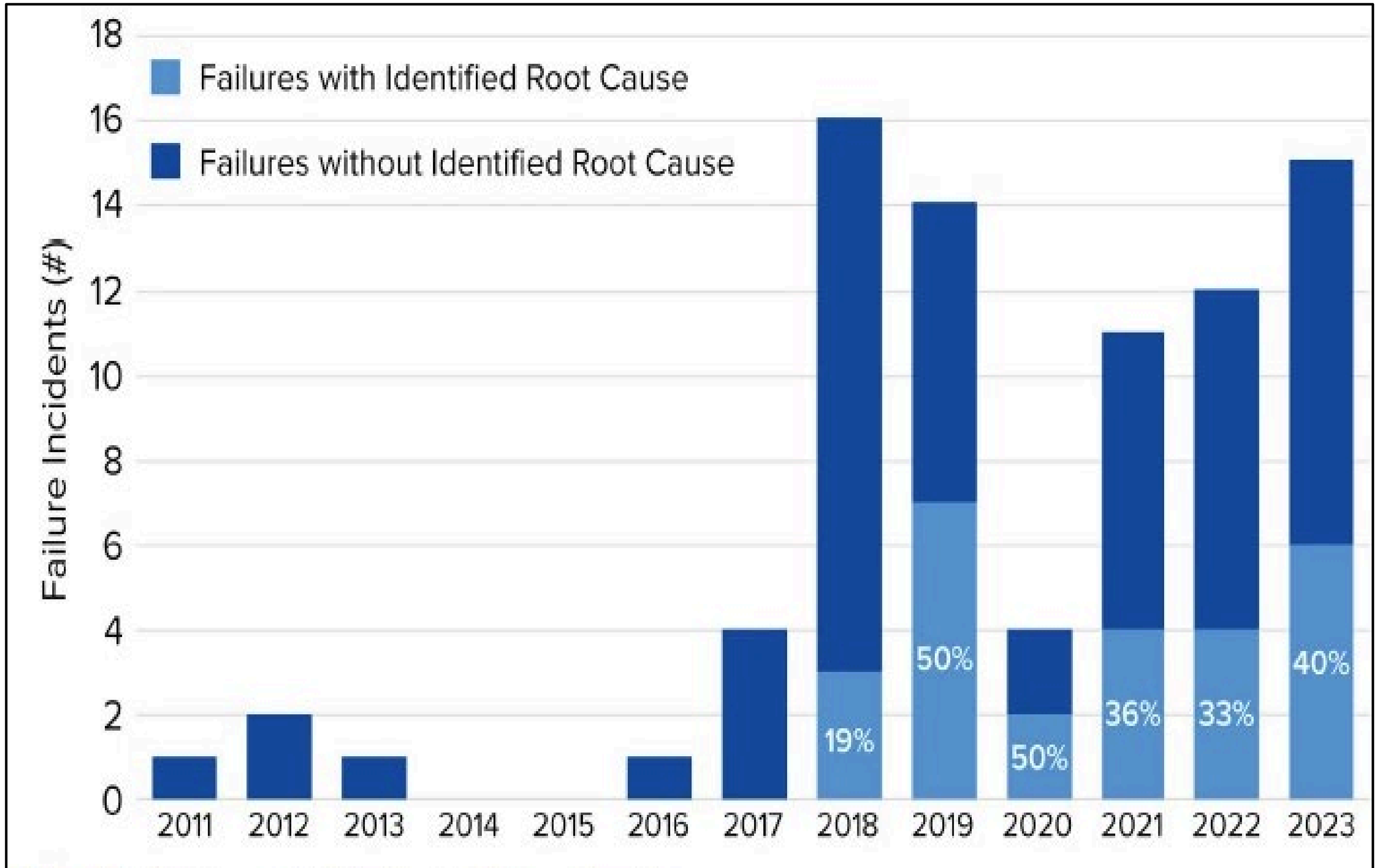


Figure 3. BESS Failures with Identified Root Cause Over Time

- Failures in more than one enclosures are not considered

- Hazards during construction, shipping and storage are not evaluated

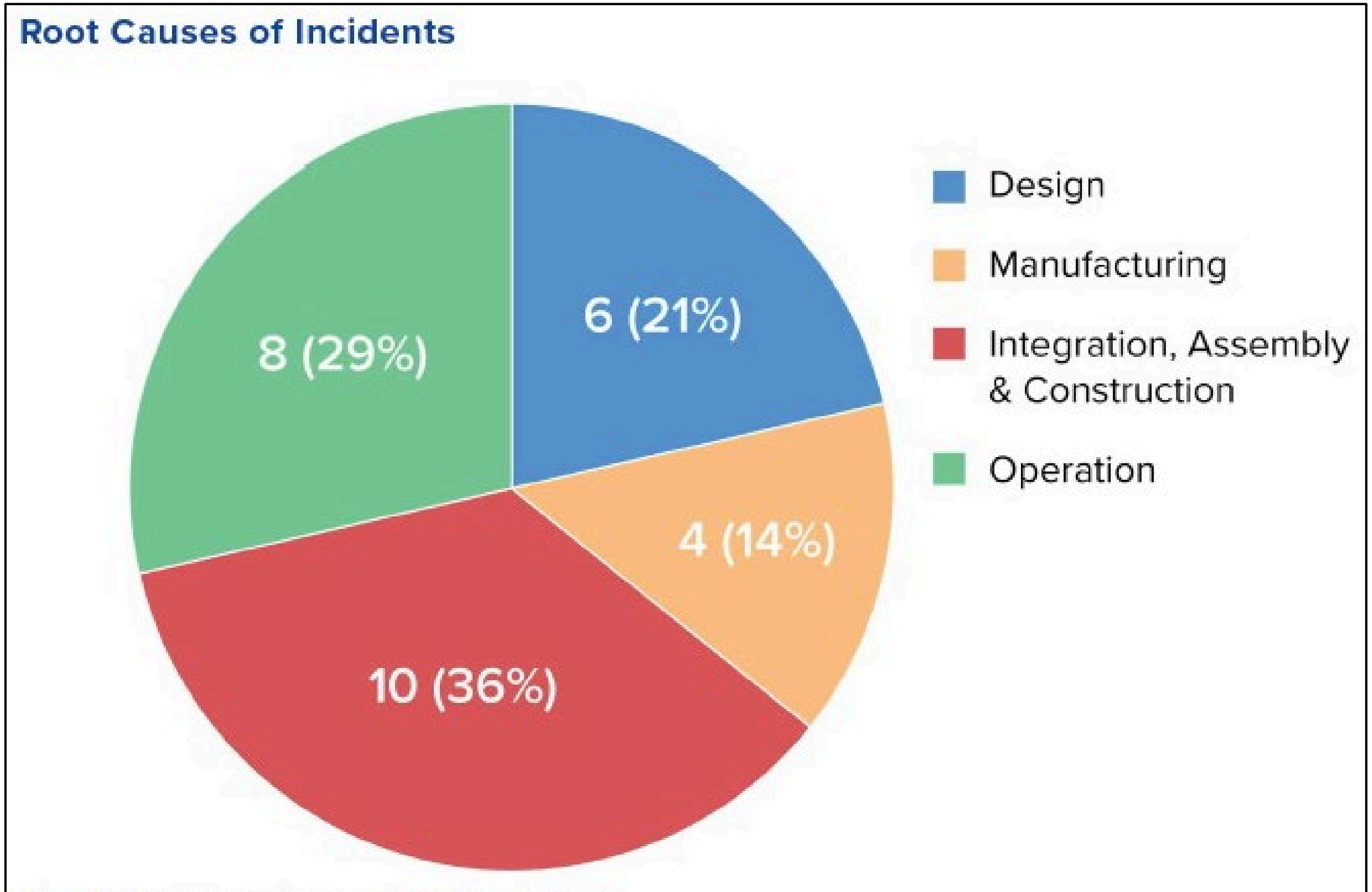


Figure 4. Breakdown of BESS Failures by Root Cause

- Protection systems inside the BESS enclosure and site wide must be installed per regulatory requirements. This has not been verified

Other causes of fires and failures

Cell failure test method performed for the module level (summary of method and test clause):

☒ External heating using thin film with 4°C to 7°C thermal ramp.

☐ Nail Penetration ☐ Overcharge

☐ External short circuit (*X Ω external resistance*)

☐ Others

- Balance of system fire, initiated in wire insulation, electrical components, or plastic inside the system

- High temperatures inside during normal operation, loose connections, blunt force to the battery system, water damage, external fire, dust-dirt-particulate accumulation, human error, HVAC failure, sensor failure, BMS failure, site control failures, shutdown failure

More than a quarter of energy storage systems have fire detection and suppression defects: report

Defects such as faulty smoke and temperature sensors may be more common than some expect, according to clean energy advisory firm Clean Energy Associates.

Published Feb. 13, 2024 • Updated Feb. 23, 2024

- Hazardous voltage conditions, and ground- and isolation faults

The 20 most destructive California wildfires

At least eight of California's most destructive wildfires had either electrical or power line causes. Those fires are shown in **bold**.

YEAR	NAME	STRUCTURES DESTROYED	YEAR	NAME	STRUCTURES DESTROYED
2018	**Camp**	**18,804**	2018	Carr	1,614
2017	**Tubbs**	**5,636**	2020	Glass	1,520
2025	Palisades (under investigation)	5,316	2020	LNU Lightning Complex	1,491
2025	Eaton (under investigation)	>5,000	2020	CZU Lightning Complex	1,490
1991	Tunnel	2,900	**2017**	**Nuns**	**1,355**
2003	Cedar	2,820	**2021**	**Dixie**	**1,311**
2020	North Complex	2,352	**2017**	**Thomas**	**1,063**
2015	**Valley**	**1,955**	2021	Caldor	1,003
2007	**Witch**	**1,650**	2003	Old	1,003
2018	**Woolsey**	**1,643**	1999	Jones	954

Source: CalFire · By The New York Times

Batteries are often the victims of BESS safety incidents

"As a test method, UL 9540A testing does not provide a certification or pass/fail results," said Maurice Johnson, business development engineer with UL's Energy Systems and e-Mobility group. "The best way for manufacturers to share that their energy storage battery products have been tested for thermal runaway is to list them in the UL 9540A test database."

Several reports were withheld from the public:

- A draft copy from the UL9540 listing report
- Deflagration Test Report (Per the Atar report: during that test an internal divider wall collapsed)
- Preliminary Dispersion and Deflagration Modeling Progress Report
- Vigilex NFPA A68 DesignCalcs

The draft preliminary HMA report was redacted at crucial point and only became available through court procedures.

McMicken Report
Today's standards are reluctant to prescribe that a battery module <u>shall not</u> cascade from cell to cell Standards are intentionally technology-agnostic and should not impose restriction on an industry that could increase cost

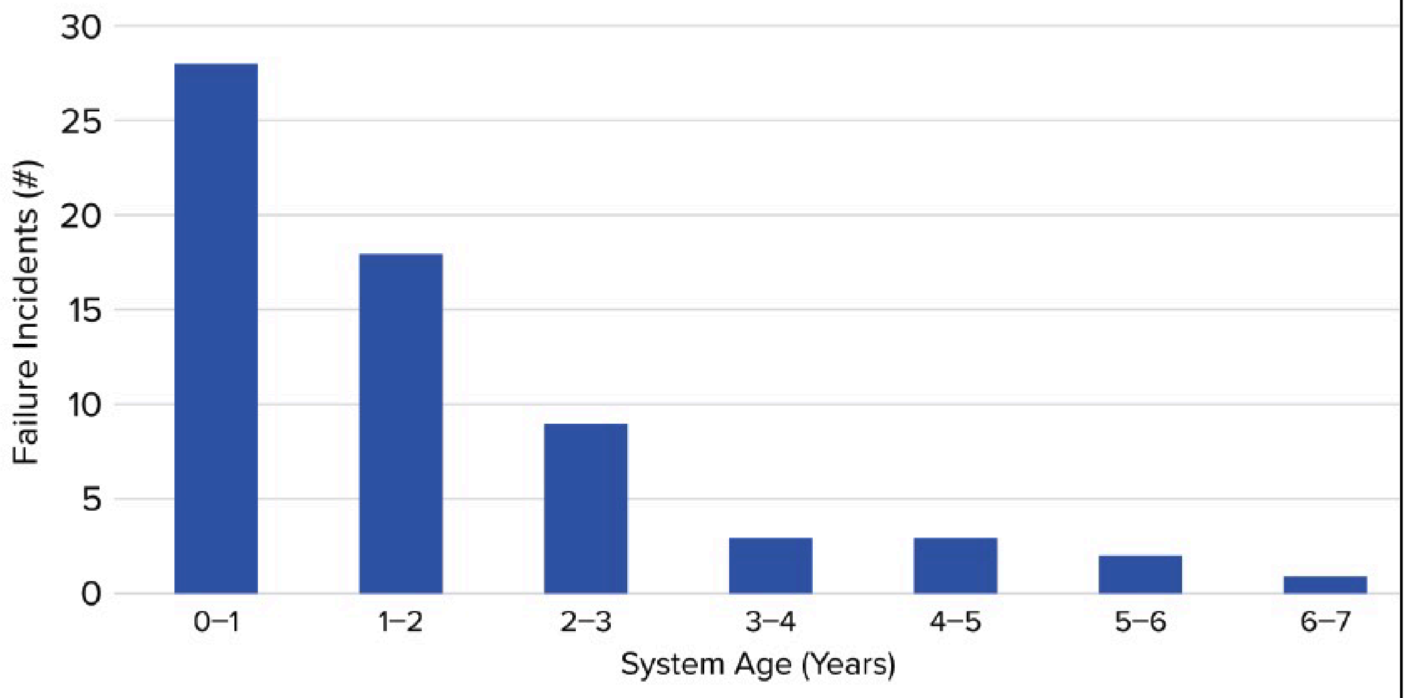
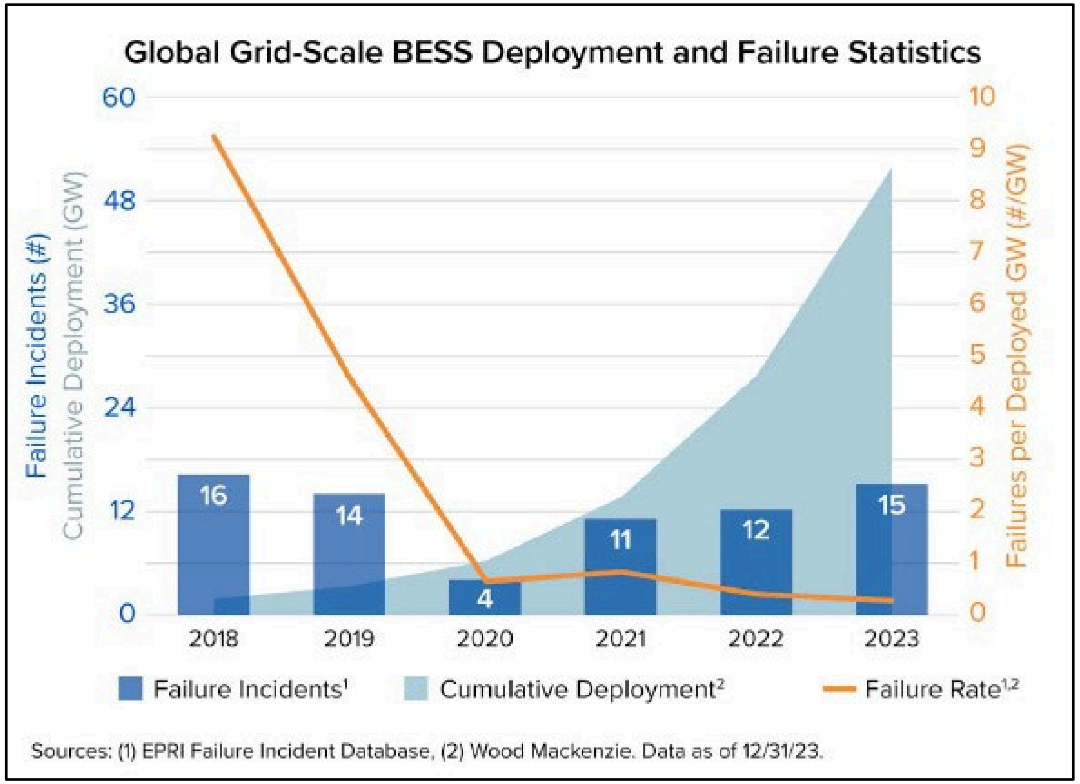


Figure 5. *BESS Age at Failure, where known*

Electric Power Research Institute EPRI



	Stationary BESS failure incidents	Other lithium ion storage failure incidents
2020	4	-
2021	11	5
2022	12	7
2023	15	5
2024	6	15
2025	1	-

EPRI data

Location	Age at incident
Moss Landing	0.5
Moss Landing	0.8
Moss Landing	1
Moss Landing	4
Escondido	7.6
San Diego	3.7
Idaho Melba	Pre-commission
Valley Center	0.2 and 1.6
NY, Warwick	0.1 and 0.1
NY, East Hampton	4.8
Rio Dell	4
AZ Chandler	3
AZ Surprise	2.1

https://storagewiki.epri.com/index.php/BESS_Failure_Incident_Database

200.000 Panels

- Fires start at cables and connectors going into the panels, and the external electrical cabinets and inverters

- Electrical shorts, flying sparks, heat buildup inside. “Avian incident” in California 2019 fire

- Risks are underestimated and underreported

- 430 cases 50% was in the panels themselves
- 25% were serious fires, difficult to extinguish and spread beyond the area

- Continue generate DC current, which is more unpredictable and difficult to protect than AC power (fire fighter safety)

- Environmental pollution due to the toxic smoke and toxic materials in the panels, could leak and contaminate the groundwater, serious impact on biodiversity

Solar farm fire in California destroys 1,127 acres

The United States doesn’t centrally track solar panel fires – with the National Fire Data Center classifying them in the “other” category.

Aerial footage of the blaze at Finley Solar Farm

Property values

Hearing Officer
The Applicant provided market studies to support its position that the siting of the Project would not negatively affect home values. The comparable properties were located in the vicinity of much smaller solar generation and battery storage facilities, 10 to 20 megawatts. Of the three properties near such facilities of approximately 100 megawatts, one was sited in an industrial area and the other was neighboring an asphalt facility

Kirkland 2023
The criteria that typically correlates with downward adjustments on property values such as noise, odor, and traffic all indicate that a solar farm is a compatible use for rural and suburban residential transition areas and that it would function in a harmonious manner with this area.

5 – Diablo Energy Storage System

This 200 MW battery storage system is located on a parcel with significant adjacency to industrial uses and residential uses. For these reasons it would be difficult to measure impacts due to the other adjoining industrial uses that might also have an impact. Given that most of the adjoining uses are industrial, I have not dug further on this one.

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Check for updates

Shedding light on large-scale solar impacts: An analysis of property values and proximity to photovoltaics across six U.S. states

Salma Elmallah [a,*], Ben Hoen [a], K. Sydny Fujita [a], Dana Robson [a], Eric Brunner [b]

[a] *Energy Analysis and Environmental Impacts Division, Lawrence Berkeley National Lab, 1 Cyclotron Road, Berkeley, CA, 94720, USA*
[b] *Department of Public Policy, University of Connecticut, 10 Prospect Street, Hartford, CT, 06103, USA*

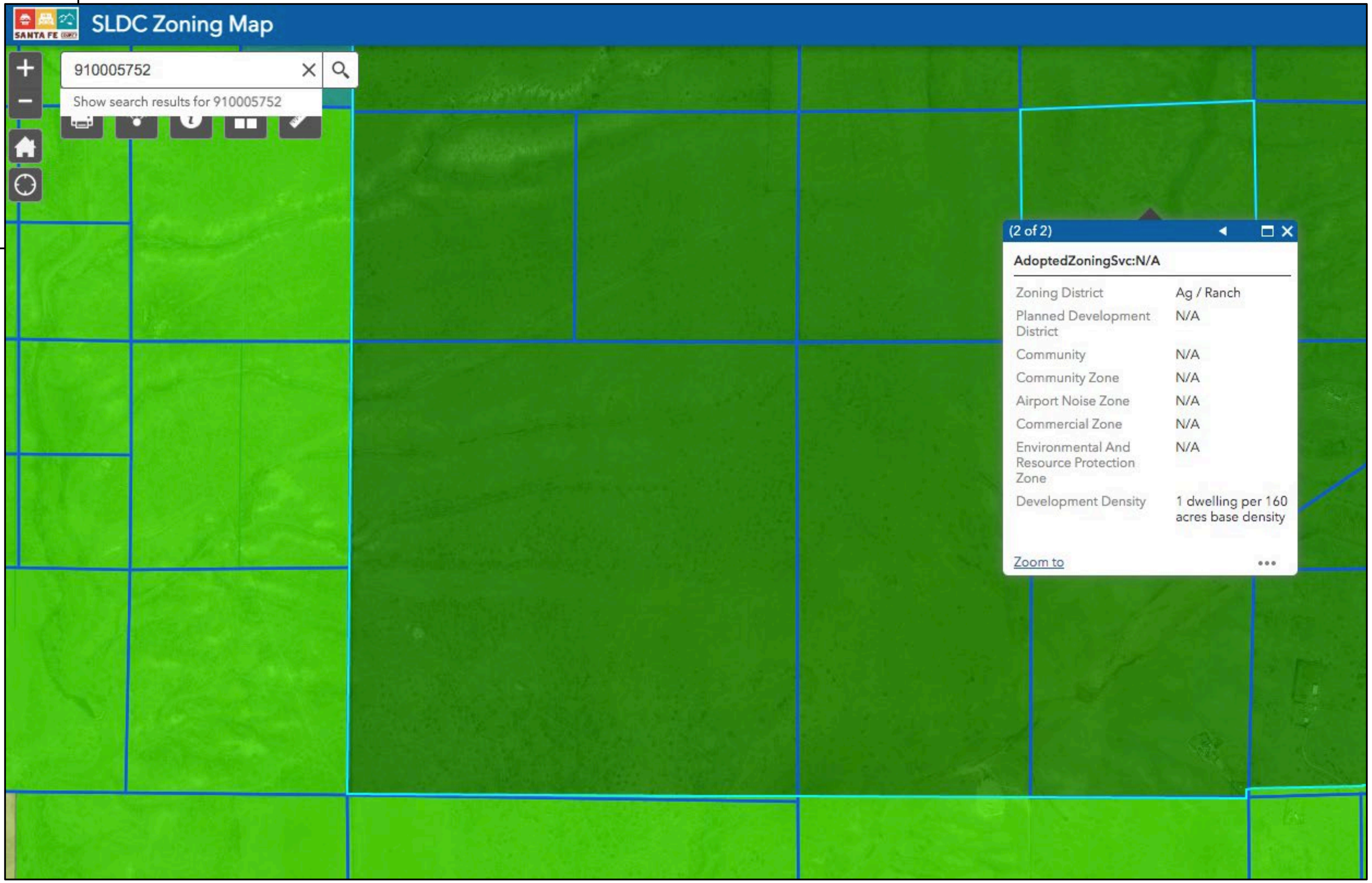
- Lawrence Berkeley National Laboratory looked at residential home prices in six states that together account for over 50% of the installed capacity of large-scale in the United States
- The study is the largest so far looking at how solar installations affect property values
- The researchers found the area where a solar installation is built has an enormous impact on whether it affects nearby home prices
- Homes in rural and agricultural areas saw declines in home prices, especially where solar farms were replacing agricultural land uses, as opposed to urban or suburban installations which saw no change in home prices
- The projects also tended to be medium-sized, most fewer than 35 acres. Large solar installations tend not to be built near areas where there are nearby homes that sold
- For homes within 0.5 miles of a large-scale solar project compared to 2-4 miles away they found a reduction in home sale prices in MN (4%) in NC (5.8%) and NJ (5.6%)
- Large-scale solar project developed on previously agricultural land, near homes in rural areas and extremely large solar project were found to be linked to adverse home sale price impacts within 0.5 mile

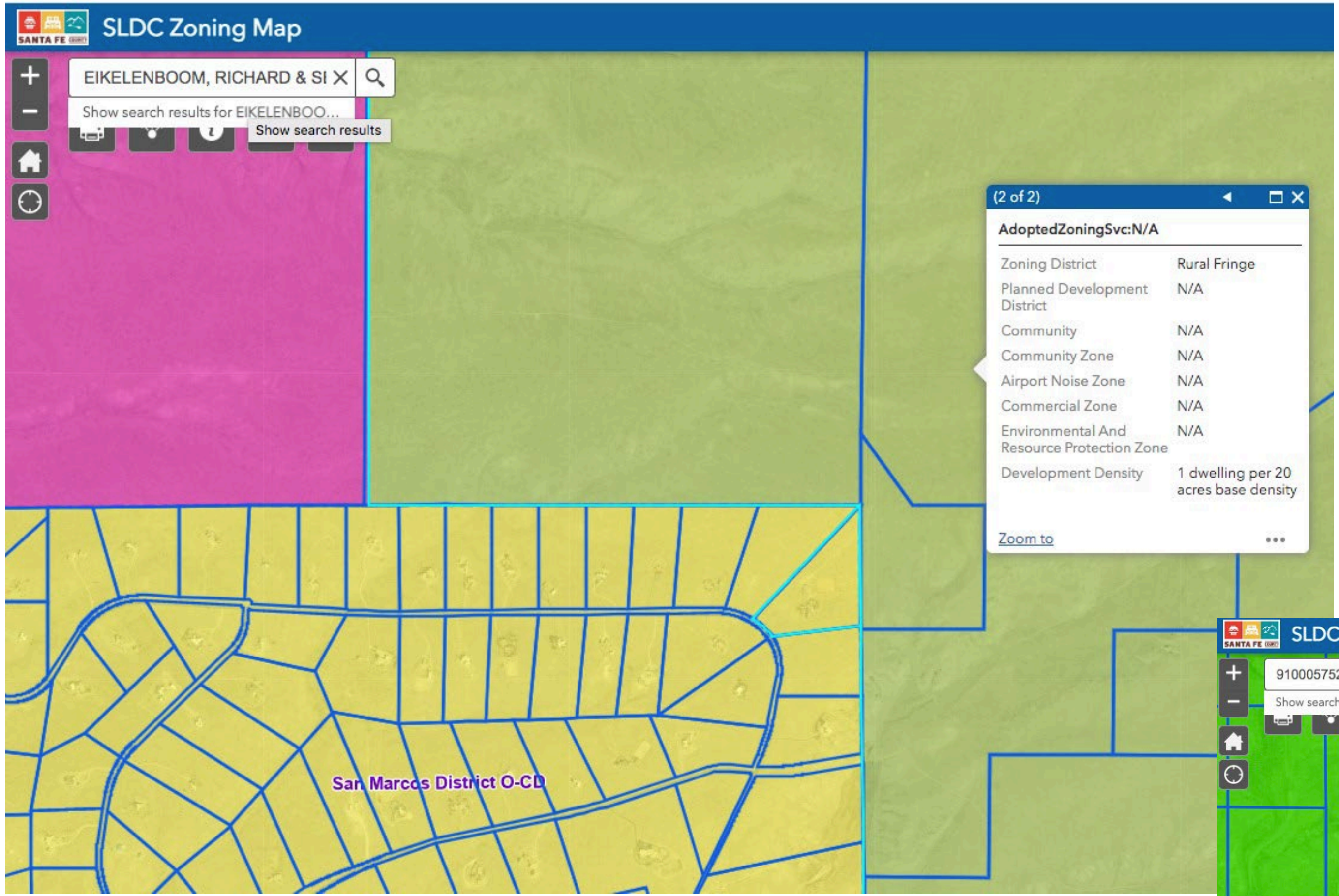
LINEA ENERGY

RENEWABLES REENVISIONED

3 times as large
Gen-tie line 0.1 mile
No update to connect to the grid
Zoning allowed

AES 2.3 mile
Upgrade transmission station

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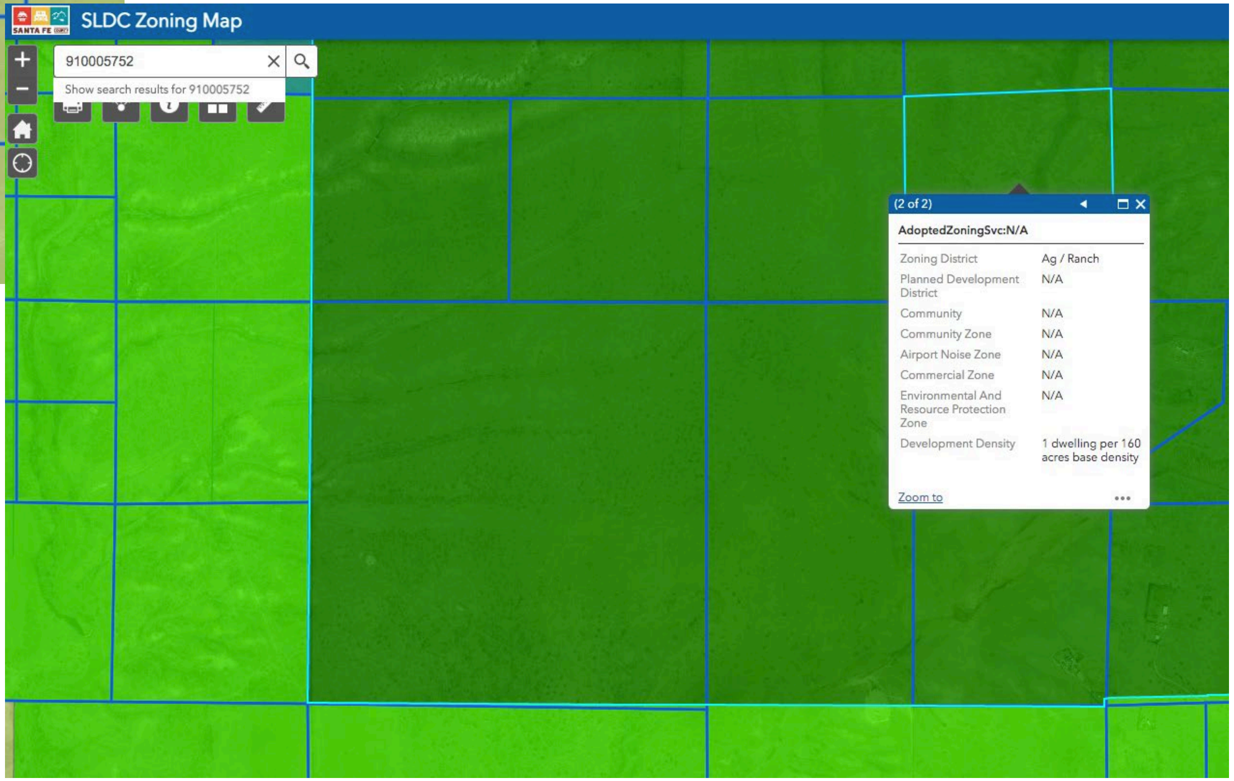
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