



E-STORAGE SOLBANK 3.0 BATTERY ENERGY STORAGE SYSTEM

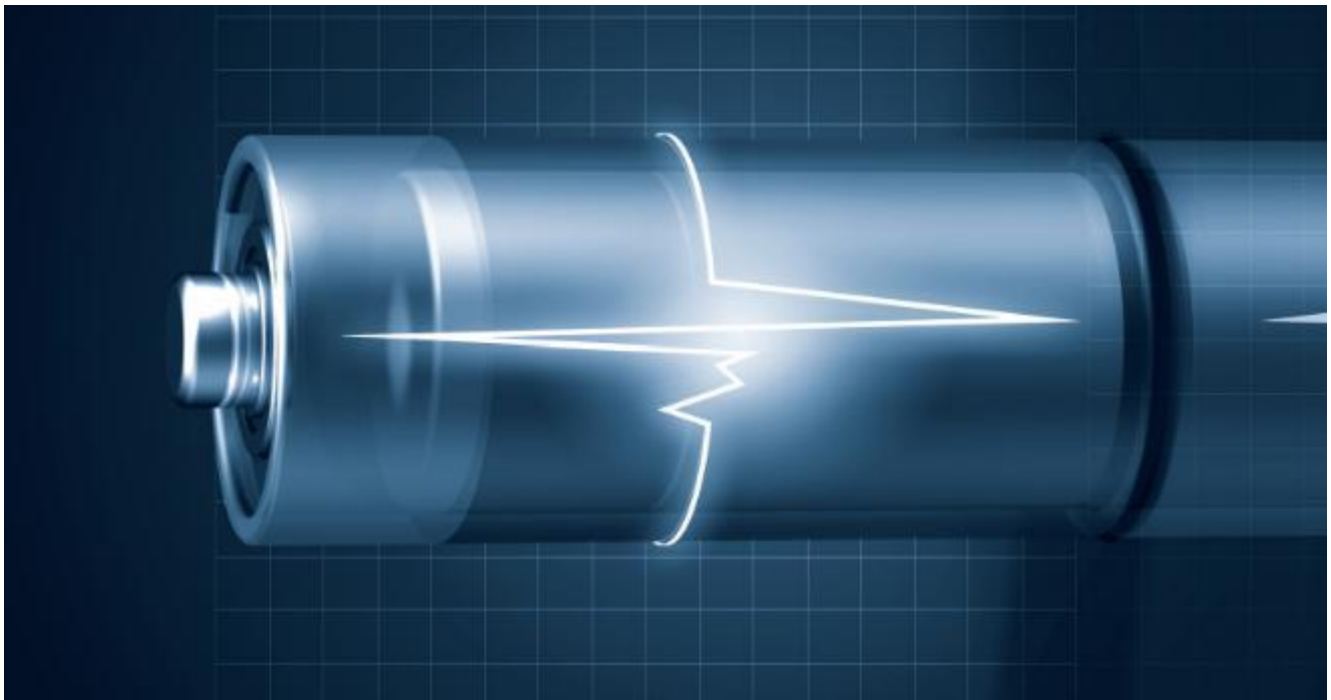
Technology Review Report

Canadian Solar SSES (US) Inc.

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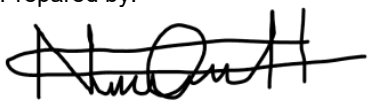
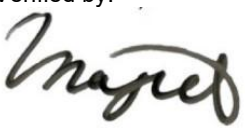


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Task and objective:
This report presents the results of analysis conducted by DNV on behalf of Canadian Solar SSES (US) Inc..

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List of abbreviations

Abbreviation	Meaning
ANSI	American National Standards Institute
BCM	Battery cluster module
BESS	Battery energy storage system
BMS	Battery management system
BMU	Battery management unit
BOL	Beginning of life
EPC	Engineering, procurement, and construction
CSI	Canadian Solar Inc
CFD	Computational fluid dynamics
CNAS	China National Accreditation Service for Conformity Assessment
CSE	Canadian Solar e-STORAGE
DC	Direct current
DOD	Depth of discharge
DMC	Distribution and control cabinet
EVE	EVE energy Co., Ltd
ESS	Energy storage system
ERG	Emergency response guide
ERP	Emergency response plans
FACP	Fire alarm control panel
FSS	Fire suppression system
GEC	Guaranteed energy capacity
Hithium	Xiamen Hithium New Energy Technology Co., Ltd
HMA	Hazard mitigation analysis
HMI	Human machine interface
IEC	International electrotechnical commission
IP	Ingress protection
PPE	Personal protective equipment
PV	Photovoltaic
PTC	Positive temperature coefficient
LER	Light Electric Rail
LFP	Lithium iron phosphate
LOTO	Lock out tag out
LTSA	Long term service agreement
NRTL	Nationally recognized test lab
NTP	Notice to proceed
OCV	Open circuit voltage
O&M	Operations and maintenance
OEM	Original equipment manufacturer
RTE	Round-trip efficiency
SOC	State of charge
SOH	State of health
UL	Underwriters Laboratories

EXECUTIVE SUMMARY

Overview

Canadian Solar SSES (US) Inc. ("CSI", "e-STORAGE" or the "Customer") retained DNV Energy USA Inc. ("DNV") to conduct a due diligence review of the SolBank 3.0 and SolBank 3.0 Plus battery energy storage system ("BESS" or "ESS").

SolBank 3.0 is a stationary BESS designed for a wide range of applications, including both standalone and grid-connected setups. This system comprises the battery, monitoring and controls equipment, along with essential auxiliary equipment, such as a thermal management system, to form a complete DC-side solution. SolBank 3.0 represents an evolution from e-STORAGE's earlier SolBank 1.0, incorporating advancements and improvements to enhance its performance and reliability in various energy storage scenarios.

Company Overview

CSI is a vertically integrated solar and energy storage solutions provider, founded in 2001 in Ontario, Canada. Initially, CSI produced portable solar chargers for automobile batteries but expanded into manufacturing solar systems for residential and commercial installations. CSI operates globally, developing photovoltaic (PV) and BESS projects, and providing engineering, procurement, and construction (EPC) services. The company employs over 22,000 people and serves customers in more than 150 countries.

The Canadian Solar e-STORAGE team, rebranded from System Solutions and Energy Storage (SSES) in 2023, leverages CSI's strengths to offer turnkey BESS for the utility-scale market. e-STORAGE began developing its proprietary utility-scale BESS, SolBank, in early 2021 and has been deploying utility-scale BESS on projects since 2021.

Financially, CSI reported as of 31 March 2026, net revenue of USD \$1.1 billion. As of 8 May 2026, e-STORAGE contracted backlog, including contracted long-term service agreements, was USD \$3.5 billion.

Hardware Review

SolBank 3.0

e-STORAGE's SolBank 3.0 utility-scale BESS has a rated capacity of 5.016 MWh. This third-generation product is fully factory-integrated, featuring 314 Ah lithium iron phosphate (LFP) cells, a battery management system (BMS), and a liquid cooling thermal management system. e-STORAGE offers the SolBank 3.0 equipped with cells from multiple suppliers including Hithium, e-STORAGE, EVE, Cornex, and Sunwoda.

SolBank 3.0 is offered in both 2-hour and 4-hour versions. The 2-hour version (CSI-SolBank-S-5016-2h) has a usable energy capacity of 4,700 kWh, nominal power of 2,350 kW, and a beginning of life (BOL) round-trip efficiency (RTE) of 93%. The 4-hour version (CSI-SolBank-S-5016-4h) has a usable energy capacity of 4,800 kWh, nominal power of 1,200 kW, and a BOL RTE of 94%. DNV reviewed the product specifications and found them to align with other similar products in the industry.

SolBank 3.0 Plus

SolBank 3.0 Plus is a utility-scale BESS that features Cornex 314 Ah pre-lithiated LFP cells. SolBank 3.0 claims up to 12,000 cycles for a 25-year design life and a nominal capacity of 5,016 kWh. It comes in two configurations: 2-hour and 4-hour discharge durations. It operates in ambient temperatures from -30 °C to 55 °C and altitudes up to 4,000 m, with

derating above 45 °C and 2,000 m, respectively. SolBank 3.0 Plus retains the same enclosure and it was publicly launched in May 2025 and is anticipated to be commercially ready by October 2026.

Operational Performance

DNV assessed the product's performance, including battery capacity, efficiency, response time, power output, and degradation. DNV reviewed data from tests on the Hithium 314 Ah LFP cell used in SolBank 3.0. DNV recommends updating this Report when data from other versions (EVE, e-STORAGE, Cornex) of the system becomes available.

Capacity performance testing showed a discharge capacity of 325.3 Ah and discharge energy of 1038.6 Wh, both exceeding targets. Rate capability testing revealed that higher temperatures enhance power capabilities, while colder environments reduce efficiency. The 314 Ah cell performed optimally at temperatures between 25 °C and 55 °C, with capacity and energy retention decreasing at lower temperatures. RTE testing at C-rates of 0.25C and 0.5C showed high efficiency, with RTE values at BOL ranging from 93.49% to 94.71%.

DNV also evaluated BESS degradation by focusing on capacity retention from cycling and calendar losses. Cyclic degradation tests showed that higher depths of discharge (DOD), temperatures, and charge/discharge rates accelerate degradation. Overall, DNV considers the SolBank 3.0 BESS performance to be in line with similar products in the industry.

Thermal Management System

SolBank 3.0 uses a liquid-cooled design to maintain optimal thermal conditions, featuring components such as a condenser, radiator, positive temperature coefficient (PTC) heaters, and pumps to circulate coolant. The system is monitored and controlled by various sensors, and coolant flow is managed by pump speed and a three-way valve.

The thermal management system aims to maintain cell temperatures within an optimal range of 20 °C to 35 °C. The chiller's cooling and heating capacities are 25 kW and 16 kW for the BTMS-250-ES model, and 60 kW and 16 kW for the BTMS-600-ES model, respectively.

The thermal management system performance for SolBank 3.0 was evaluated with the Hithium cell. SolBank 3.0 was found to have typical temperature variation during operation (within a pack and across the BESS) for a liquid cooled BESS, which predicts low risk for uneven aging between cells. The maximum cell temperatures observed during operational testing were favorable, but the ambient conditions of the test were unknown. As such, DNV is unable to opine on the risk of accelerated degradation.

Safety program and certification

SolBank 3.0 and its components comply with various safety standards, including UL and IEC certifications. Key standards include UL 1973 for battery modules, UL 9540 for the full DC system, and UL 9540A for thermal runaway testing. These standards ensure the system's design meets minimum safety requirements and best practices. Additional IEC certifications, which are used more broadly in other countries, for the battery cells and units were also reviewed.

SolBank 3.0's safety design includes an enclosure with an IP55 rating, which provides protection against dust and water. The fire protection system includes three smoke detectors, three heat detectors, one fire alarm control panel (FACP), one audio and visual alarm, four optional aerosol FSS and one optional spray FSS. The FACP monitors all protection devices and interfaces with the BMS, with a UPS backup for 24-hour power. The system also includes two emergency stops and floor drains to remove any leaked substances. SolBank 3.0 is equipped with explosion protection features, including two hydrogen gas detectors, a ventilation fan, two air intake blinds, and five optional deflagration panels. Safety controls include

alarms for combustible gas levels, smoke, and heat, with specific actions defined for each alarm level to manage the system's operational status

DNV reviewed NFPA 69 analysis reports for SolBank 3.0 utilizing Hithium, e-STORAGE, EVE, Cornex, and Sunwoda cells, and notes that the explosion prevention system complies with the requirements of NFPA 69 across all evaluated cell types. DNV also reviewed the NFPA 68 analysis reports for SolBank 3.0 utilizing Hithium, e-STORAGE, and Cornex cells and notes that explosion protection system complies with the requirements of NFPA 68 for the Hithium, e-STORAGE, and Cornex cell variations. DNV has not reviewed NFPA 68 for EVE and Sunwoda cells, as testing remains incomplete. e-STORAGE has informed DNV that no projects currently require deflagration panels; therefore, compliance should be evaluated on a project-specific basis.

DNV also reviewed the draft Hazard Mitigation Analysis (HMA) and draft Emergency Response Guide (ERG) for SolBank 3.0. DNV recommends that the draft HMA and draft ERG be finalized before any field installations. The draft ERG outlines procedures for emergency response planning, including fire protection, risk evaluation, and response coordination. While the draft ERG is robust and aligns with industry best practices, DNV recommends updating it with site-specific information for each project.

Process review findings

Installation and integrated system requirements

DNV evaluated SolBank 3.0's installation and integration processes by reviewing the installation manual which covers safety protocols, installation instructions, and post-installation guidance. The installation process includes securing the equipment, marking foundations, developing a lifting plan, and ensuring proper placement and connection of the SolBank 3.0. After installation, inspections are conducted to check structural integrity, electrical connections, and the functionality of the fire protection system. The manuals also detail space and site requirements, including specific clearance distances and foundation preparations. DNV finds the installation processes to align with expectations.

In addition, DNV also reviewed SolBank 3.0's user manual, maintenance manual, and commissioning manual. Overall, DNV finds the manuals to be detailed and adequate for on-site integration, with recommendations for updates as needed.

Manufacturing and quality

e-STORAGE informed DNV that mass production of SolBank 3.0 will take place in the same factories as SolBank 1.0, located in Suzhou and Dafeng, China. As of Oct 2024, the production lines are being upgraded to accommodate the new battery pack and final enclosure assembly, while maintaining the same quality system and ISO certifications as SolBank 1.0.

DNV evaluated the manufacturing and quality systems for SolBank 3.0, noting that e-STORAGE's facilities responsible for integrating the SolBank 3.0 hold ISO 9001:2015, ISO 14001:2015, and ISO 45001:2018 certifications, which aligns with expectations. DNV conducted site visits to CSI's manufacturing facilities in China, in January and March 2025. The visits aimed to assess quality control procedures and manufacturing processes. During the audits, several issues were identified, including document control, warehouse management, and supplier evaluations. CSI responded with thorough root cause analyses and implemented corrective actions, demonstrating strong quality control awareness and commitment to continuous improvement. The Dafeng Factory's automation and quality control systems were found to meet or exceed industry standards. In addition, DNV plans to conduct a site visit to the Thailand facility for SolBank 3.0 in July 2026, with findings to be incorporated into a subsequent revision of this report.

Overall, DNV considers CSI's manufacturing site audits to be in line with industry expectations.



Product service infrastructure

e-STORAGE uses an in-house software called CSEye for 24/7 remote monitoring, diagnostics, and troubleshooting of their energy storage systems, generating detailed performance reports, and managing spare parts inventory. SolBank 3.0 limited warranty, which covers component defects and capacity shortfalls for up to 20 years, with specific terms for liquidated damages in case of shortfalls. The warranty includes operating limits and a capacity guarantee, ensuring the storage capacity remains above a certain threshold. DNV found these terms consistent with industry standards. Additionally, e-STORAGE offers Long-Term Service Agreements (LTSA) covering comprehensive O&M services, with options to extend coverage.

DNV also reviewed the safety and decommissioning manuals for SolBank 3.0, which outlines procedures for safely disassembling and removing the system, ensuring compliance with safety regulations and guidelines. DNV considers the procedures to be aligned with typical industry expectations.

1 INTRODUCTION

Canadian Solar SSES (US) Inc. ("Canadian Solar" or the "Customer") retained DNV Energy USA Inc. ("DNV") to conduct a due diligence review of the e-STORAGE SolBank 3.0 Battery Energy Storage System and SolBank 3.0 Plus battery energy storage system (BESS). This Report presents the results of DNV's analysis.

1.1 Objective and scope of review

The primary objective of this Report is to assess factors that would affect the final product's performance and reliability in the field and the Company's ability to deliver and service the products. Such factors will include the product design, quality of materials, product performance, regulatory compliance, reliability tests, and the manufacturing and quality control processes.

DNV has divided the Technical Review into several main topic areas for evaluation:

- Company overview
- Battery product overview
- Battery review, including the cells, modules, thermal management system and battery management system
- Safety and certifications validation
- Communication, controls, and software review
- Integrated system operational performance evaluation
- Integration and installation requirements
- Manufacturing, supply chain, and quality review
- Service infrastructure

Key findings are gathered in the executive summary of the Report.

1.2 Methodology

In general, this Report contains information that would be included in a final Independent Engineering review intended for financial institutions, Canadian Solar customers, and project developers. DNV is uniquely qualified to conduct this study due to its extensive background and experience in solar, wind, and energy storage independent engineering and technology due diligence work.

To perform the assessment, DNV relied on documentation provided by Canadian Solar and conversations with key staff associated with the topic areas covered. DNV has visited Canadian Solar's production and manufacturing sites, and the results of those assessments have been included in this Report.

As noted above, where applicable DNV will draw on previous technology review work performed with Canadian Solar. Where used, permission was acquired for the use of this information.

Information was aggregated from multiple Canadian Solar sources and provided to DNV for generation of this Report by:

- Jason Zhang: Senior Director, System Technical Solutions & Applications
- Sreedevi Kandankavil: Technical Solutions Engineer

1.3 Assumptions

This Report summarizes the DNV assessment of the technology and relies on the accuracy of the information provided by Canadian Solar. Canadian Solar has been generally forthcoming in providing the data that DNV has requested; where data



was not provided or was incomplete is noted as such within the Report. Some data received from Canadian Solar that has been used in the production of this Technology Review has been omitted from this Report based on requirements from Canadian Solar that it remains confidential.

This Report is based on some information not within the control of DNV. DNV believes that the information provided by others is true, correct, and reasonable for the purposes of this Report. DNV has not been requested to make an independent analysis or verification of the validity of such information. DNV does not guarantee the accuracy of the data, information, or opinions provided by others.

In preparing this Report and the opinions presented herein, DNV has made certain assumptions with respect to conditions that may exist, or events that may occur in the future. DNV believes that these assumptions are reasonable for the purposes of this Report, but actual events or conditions may cause results to differ materially from forward-looking statements.

2 COMPANY EVALUATION

2.1 Company overview

CSI is a vertically integrated solar and energy storage solutions provider. It was founded in 2001, Ontario, Canada. Initially, the company produced portable solar chargers for automobile batteries. Over time, it expanded into manufacturing solar systems for residential and commercial installations. By 2006, CSI went public on the NASDAQ stock exchange, raising capital to support its growth [1].

CSI has two main lines of business involved in storage projects, which are summarized below:

- Canadian Solar Inc. (CSIQ): Under the ultimate parent company (Canadian Solar Inc., CSIQ), several entities including CS PowerTech Inc. (US), CSI Energy Storage Technology (Thailand) Co., Ltd. and CSI Solar (China) focuses on manufacturing solar modules and BESS, and delivering system solutions, including inverters, solar system kits, and EPC services. The e-STORAGE branded BESS business offers utility-scale turnkey BESS solutions. These solutions are supported by long-term service agreements, including future battery capacity augmentation services.
- Recurrent Energy: This division is the technology, manufacturing, and EPC (engineering, procurement, and construction) arm of CSI, with 15 years of experience. It is vertically integrated, handles greenfield origination, development, financing, execution, operations and maintenance (O&M), and asset management.

CSI, through its subsidiaries, operates globally as a developer of photovoltaic (PV) and BESS projects. It also provides engineering, procurement, and construction (EPC) services, with regional teams supporting different phases of development, construction, and operations. Recurrent Energy has a stated pipeline of 25 GWp of solar projects and 83 GWh of storage projects.

Within CSI, the Canadian Solar e-STORAGE (herein referenced as “e-STORAGE” or “CSE”) team leverages CSI’s organizational strengths to offer turnkey BESS for the utility-scale market. e-STORAGE leverages over 50 years of combined storage experience, as well as CSI central procurement strategies. e-STORAGE had been deploying utility-scale BESS projects since 2019 under a group known as System Solutions and Energy Storage (SSES) and was rebranded as e-STORAGE in 2023 [2]. As of 31 December 2025, CSI has over 22,000 employees and operates on six continents with customers in over 150 countries, see Figure 2-1.

The e-STORAGE team offers three types of services, covering both standalone storage and PV + storage solutions: design services, turnkey BESS project development, and BESS system O&M. Design services include system-sizing modelling, integrated power electronics design, and system controls solutions. e-STORAGE delivers wrapped turnkey energy storage solutions consisting of containerized battery modules, as well as supporting equipment. e-STORAGE also offers warranties and performance guarantees for their systems. O&M services offered include, but are not limited to, site monitoring, periodic routine reporting, preventive and corrective maintenance, as well as warranty and spare parts management.

As of 8 May 2026, the contracted backlog, including contracted long-term service agreements, was USD \$3.5 billion. These are signed orders with contractual obligations to customers, providing significant earnings visibility over a multi-year period [3].



Figure 2-1 CSI Global presence

DNV recognizes the CSI organization and its subsidiaries as an industry leading organization. DNV notes that e-STORAGE is backed by the CSI organization and is integrated with CSI's vast resources of executing utility scale projects globally which has added to the e-STORAGE team's experience in integration of BESS into their project pipeline.

2.2 Company financials and sales revenues

DNV reviewed CSI's financial results from the first quarter of 2026 [4]. The highlights are as follows:

- e-STORAGE's contracted backlog grew to \$3.5 billion as of 8 May 2026.
- As of March 2026, e-STORAGE had over 12.5 GWh of operating BESS projects contracted under both long-term service agreements (LTSA) and non-LTSA.
- Recurrent Energy had a solar development pipeline of 24 GWp and a BESS development pipeline of 81 GWh as of 31 March 2026.
- CSI's net revenues of \$1.1 billion in Q1 2026.
- CSI's gross profit in the first quarter of 2026 was \$271 million, inclusive of a \$93 million tariff refund benefit, compared to \$124 million in Q4 2025.

DNV considers CSI's financial outlook to be in line with industry expectations.

2.3 Stationary energy storage product history

In early 2021, e-STORAGE began the development of its proprietary utility-scale BESS called SolBank. The SolBank product is a liquid cooled, fully integrated energy storage system, which can be configured as an ac coupled or dc coupled architecture. It utilizes LFP battery cell technology manufactured by various cell suppliers including: e-STORAGE, EVE Energy Co., Ltd. (EVE), Xiamen Hithium New Energy Technology Co., Ltd. (Hithium), and Cornex New Energy Co., Ltd (Cornex). Figure 2-2 highlights the evolution in BESS technology, focusing on improvements in energy capacity, efficiency, thermal management, and safety features (see Section 3 herein for details).

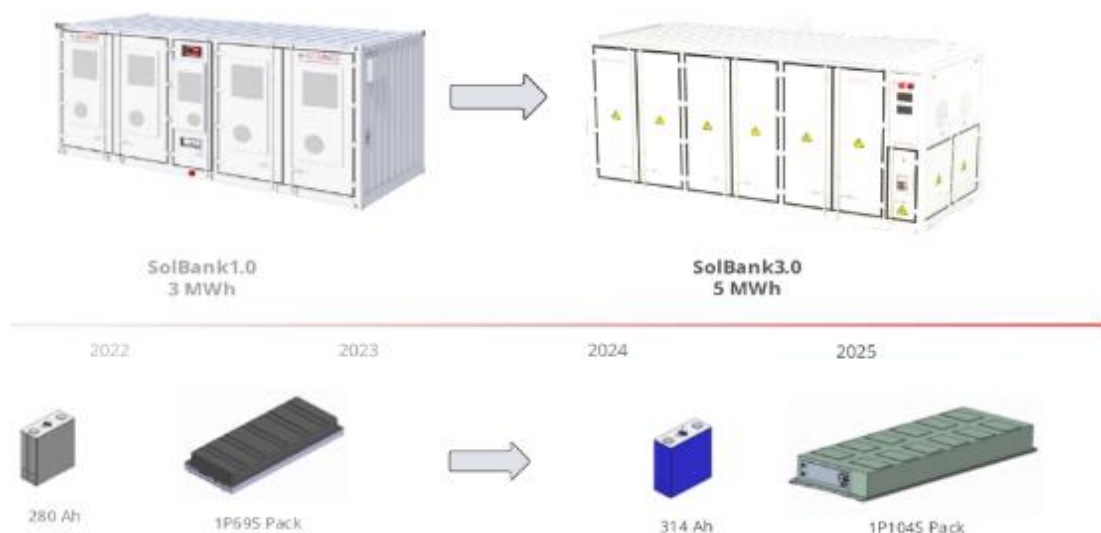


Figure 2-2 e-STORAGE's product evolution over the years

e-STORAGE has shared a list of deployed/operational, under construction, pre-construction and under contracting projects with DNV [5], see Table 2-1. Starting from 2023, all projects have adopted SolBank. This includes projects that are currently in the contracting phase, which encompasses agreements for SolBank versions 1.0, 2.0, and 3.0. In addition, e-STORAGE provided a detailed overview of various energy storage projects utilizing SolBank technology across the globe. It lists projects by their names, locations, capacities in megawatts (MW) and megawatt-hours (MWh), and their commercial operation dates (COD). The projects span multiple countries, including the USA, Canada, UK, China, Japan, Australia, and Chile, and cover both operational and under-construction sites. Notable projects include the Slate project in California with a capacity of 140 MW and 560 MWh, and the Coalburn project in Scotland with a capacity of 500 MW and 1000 MWh AC (1,261 MWh DC nominal).

In total, e-STORAGE has a combined capacity of 12,461 MWh DC in operational projects, 22,973 MWh DC in projects under construction, and 45 MWh DC in pre-construction stages. e-STORAGE has deployed 12.46 GWh of BESS across the United States, Canada, the United Kingdom, China, Japan, and Australia.

Table 2-1 e-STORAGE reference project list

Status	MW AC Usable	MWh AC Usable	MWh DC Nominal (Nameplate)
Deployed and Operational	3,789	10,281	12,461
Under Construction (Contracted/NTP)	6,374	18,503	22,973
Pre-Construction (Contracted/Pre-NTP)	10	40	45
Total	10,173	28,823	35,479

2.4 Intellectual property evaluation

e-STORAGE has developed an intellectual property portfolio that underscores its commitment to innovation and technological advancement in the battery industry. As of December 2024, e-STORAGE has filed a total of 109 patent applications in China, see Table 2-2. These patents are categorized into three main types: utility models, designs, and

inventions. The majority of the patents, 109 in total, fall under the Utility Models category. There are 10 patents categorized as Designs, and the remaining 23 patents are classified as Inventions. Out of the 109 patents, 63 have been granted, while 46 are still pending.

DNV does not provide legal advice on patent matters, it acknowledges e-STORAGE's intellectual property strategy as a positive indicator of the company's dedication to innovation and market leadership. DNV has requested information regarding whether there are patent applications in jurisdictions other than China. e-STORAGE are currently in the process of gathering this information and will provide updates once it becomes available.

Table 2-2 e-STORAGE patent portfolio

Country	Patent Type	Patent Title (Machine Translation)	Filing Date	Status
China	Utility Model	Battery racks and energy storage systems used for energy storage systems	2023-12-25	Granted
China	Utility Model	Spray system and its energy storage system	2023-12-26	Granted
China	Utility Model	Energy storage system	2023-12-26	Granted
China	Utility Model	Explosion relief device and energy storage system used for energy storage systems	2023-12-26	Granted
China	Utility Model	Energy storage device and its energy storage system	2024-02-22	Granted
China	Design	Liquid cooled energy storage cabinet	2023-12-22	Granted
China	Design	Liquid cooled energy storage cabinet	2023-12-22	Granted
China	Design	Cover on battery pack	2024-03-21	Granted
China	Invention	Testing methods for energy storage battery systems	2022-02-09	Granted
China	Design	Battery Pack	2024-02-04	Granted
China	Design	Energy storage box	2023-12-22	Granted
China	Utility Model	Energy storage cabinet	2023-11-13	Granted
China	Utility Model	Thermal management system for energy storage system and energy storage system with it	2023-10-17	Granted
China	Utility Model	Negative electrode materials and batteries	2023-11-10	Granted
China	Design	Energy storage cabinet	2023-09-28	Granted
China	Utility Model	Become a nail	2023-10-31	Granted
China	Invention	Preparation method and back contact battery	2020-12-30	Granted
China	Utility Model	Sealing structure for battery injection holes, cover plate assembly for batteries, and batteries	2023-08-21	Granted
China	Utility Model	Battery pack cover and battery pack with it	2023-08-09	Granted
China	Invention	Packaging assembly	2020-11-27	Granted
China	Utility Model	Pole components, battery cover plates, and batteries	2023-08-28	Granted
China	Utility Model	Bus integrated components and battery packs with them	2023-07-31	Granted
China	Utility Model	A battery pack	2023-07-31	Granted
China	Utility Model	Output electrode mounting bracket and its battery module, battery pack	2023-07-10	Granted
China	Utility Model	Battery pack shell and battery pack with it	2023-08-04	Granted
China	Utility Model	Battery module end plate and its corresponding battery module and battery pack	2023-07-10	Granted
China	Utility Model	Lower shell of battery pack and battery pack with it	2023-06-16	Granted
China	Utility Model	Energy storage system	2023-05-24	Granted

Country	Patent Type	Patent Title (Machine Translation)	Filing Date	Status
China	Utility Model	Cell module clamping mechanism and cell module stacking device with it	2023-03-15	Granted
China	Utility Model	Energy storage box fan	2022-12-15	Granted
China	Utility Model	Energy storage box and its bidirectional pressure relief device	2022-12-20	Granted
China	Utility Model	A battery testing rack	2022-11-09	Granted
China	Utility Model	Gas fire extinguishing cabinet and energy storage box with it	2022-12-29	Granted
China	Utility Model	Energy storage box fan	2022-12-15	Granted
China	Utility Model	A battery module feeding device	2022-11-22	Granted
China	Utility Model	A type of end plate feeding equipment	2022-11-02	Granted
China	Utility Model	Liquid cooled energy storage system and energy storage container with it	2022-10-21	Granted
China	Utility Model	Energy storage box and its corresponding energy storage fire protection system	2022-12-30	Granted
China	Utility Model	Tray mechanism and battery pack installation equipment	2022-12-27	Granted
China	Utility Model	Energy storage box	2022-12-27	Granted
China	Utility Model	Energy storage box	2022-12-20	Granted
China	Design	Energy storage battery pack (liquid cooled)	2022-09-30	Granted
China	Utility Model	Tooling and welding equipment for battery modules	2022-11-21	Granted
China	Utility Model	Cover plate components and lithium-ion batteries	2022-09-29	Granted
China	Utility Model	Battery module and its liquid cooled energy storage battery pack system	2022-09-30	Granted
China	Utility Model	Box and energy storage device for energy storage devices	2022-08-15	Granted
China	Utility Model	A type of energy storage container	2022-02-23	Granted
China	Utility Model	Energy storage container distribution combiner cabinet and energy storage container	2022-04-15	Granted
China	Utility Model	Energy storage container distribution combiner cabinet and energy storage container	2022-02-23	Granted
China	Utility Model	Energy storage system	2021-12-28	Granted
China	Utility Model	Energy storage device	2021-12-28	Granted
China	Utility Model	Energy storage container distribution combiner cabinet and energy storage container	2022-02-23	Granted
China	Utility Model	Energy storage container	2021-12-27	Granted
China	Utility Model	Battery heat exchangers and battery components	2021-12-27	Granted
China	Utility Model	Energy storage container	2021-12-29	Granted
China	Utility Model	Battery pack installation equipment	2021-12-29	Granted
China	Utility Model	Cabinets and energy storage cabinets used for energy storage	2024-11-27	Pending
China	Utility Model	Energy storage system	2024-11-18	Pending
China	Utility Model	Cover plate and battery for batteries	2024-11-07	Pending
China	Utility Model	A packaging structure for energy storage systems	2024-11-19	Pending
China	Utility Model	Pole piece components, pole cores, battery cells, and batteries	2024-11-19	Pending
China	Utility Model	Cover plate components and batteries for batteries	2024-11-18	Pending
China	Utility Model	Polar structure and process equipment for polar structure	2024-10-22	Pending
China	Utility Model	Electrode plates and process equipment	2024-09-11	Pending
China	Utility Model	Energy storage battery pack cover, energy storage battery pack, and energy storage container	2024-10-24	Pending
China	Invention	Blade battery and battery pack with it	2024-09-03	Pending

Country	Patent Type	Patent Title (Machine Translation)	Filing Date	Status
China	Invention	A composite membrane and its preparation method and application	2024-10-18	Pending
China	Design	lithium battery	2024-07-19	Pending
China	Invention	Pre lithiated thin films, their preparation methods, applications, and lithium-ion batteries	2024-07-31	Pending
China	Invention	Pre lithiated thin films, their preparation methods, applications, and lithium-ion batteries	2024-07-31	Pending
China	Invention	Energy storage control methods and energy storage systems	2024-11-20	Pending
China	Utility Model	A battery module box insertion device and battery pack	2024-08-14	Pending
China	Utility Model	A battery pack and electrical device	2024-07-23	Pending
China	Utility Model	Liquid cooling system and energy storage products	2024-08-08	Pending
China	Utility Model	A stacked cell structure and battery	2024-08-08	Pending
China	Utility Model	Energy storage cabinet	2024-07-26	Pending
China	Invention	Isolation membrane, its preparation method and application	2024-09-06	Pending
China	Utility Model	High voltage cabinets and energy storage containers	2024-07-24	Pending
China	Utility Model	Nickel plated copper foil oil removal device and treatment system	2024-10-22	Pending
China	Utility Model	Protective film for packaging battery cells and energy storage batteries with it	2024-06-21	Pending
China	Utility Model	Upper cover of energy storage device box, energy storage device box and energy storage device	2024-07-25	Pending
China	Invention	Lithium ion batteries, lithium replenishment methods, and preparation methods	2024-07-15	Pending
China	Invention	SOC calibration method, system, electronic equipment, and readable medium for energy storage power stations	2024-05-11	Pending
China	Invention	Scene reproduction method, energy management system, and equipment simulation system	2024-07-08	Pending
China	Invention	Electrode slurry and its preparation method	2024-05-16	Pending
China	Invention	Lithium ferrite composite materials, their preparation methods, and applications	2024-05-17	Pending
China	Invention	Lithium ferrite composite materials, their preparation methods, and applications	2024-05-17	Pending
China	Utility Model	Louvers and energy storage cabinets	2024-05-29	Pending
China	Utility Model	Connectors, borders, border components, and energy storage systems used for borders	2024-03-14	Pending
China	Invention	Methods for improving electrolyte infiltration rate, batteries, and battery preparation methods	2024-05-16	Pending
China	Utility Model	Liquid cooling module and energy storage system	2024-02-20	Pending
China	Utility Model	Welding fixtures	2024-02-20	Pending
China	Utility Model	Connection mechanism and energy storage system	2024-03-20	Pending
China	Utility Model	Energy storage equipment	2024-04-28	Pending
China	Utility Model	Battery pack cover and energy storage device	2024-03-21	Pending
China	Utility Model	Battery pack and energy storage device with it	2024-01-29	Pending
China	Utility Model	Energy storage system	2024-01-29	Pending
China	Invention	Data processing methods, energy management systems, and energy storage systems	2024-03-25	Pending
China	Utility Model	Battery pack and energy storage device with it	2024-01-29	Pending
China	Utility Model	Protective structures for batteries and their batteries	2024-02-02	Pending
China	Utility Model	Explosion relief plate and box	2023-12-19	Pending

Country	Patent Type	Patent Title (Machine Translation)	Filing Date	Status
China	Utility Model	Battery racks and energy storage systems used for energy storage systems	2023-12-25	Pending
China	Utility Model	Energy storage device	2023-12-29	Pending
China	Utility Model	Quick change structure and quick change system	2023-12-20	Pending
China	Utility Model	Liquid cooled energy storage tank	2023-12-29	Pending
China	Invention	Control methods, controllers, storage media, and energy storage systems for energy storage systems	2023-11-29	Pending
China	Invention	Polar plates, their preparation methods, and batteries	2023-12-28	Pending
China	Invention	Positive electrode lithium supplement additive doped with Al and Co lithium ferrite, its preparation method, positive electrode sheet and battery	2023-12-15	Pending
China	Invention	Thermal management methods, units, computer-readable storage media, and energy storage systems	2023-06-30	Pending
China	Utility Model	Thermal insulation buffer structure and battery module	2024-03-29	Pending
China	Invention	Thermal management and control methods for energy storage systems	2023-07-04	Pending
China	Invention	Energy storage fire control method and energy storage fire protection system	2022-12-29	Pending
China	Invention	A charging and discharging control method and device for an energy storage system and its battery cluster	2022-12-09	Pending
China	Invention	Battery pack voltage balancing control method, device, energy storage system and storage medium	2022-10-10	Pending
China	Invention	Control method for energy storage system	2022-07-19	Pending
China	Invention	Control system and control method for energy storage system	2022-07-08	Pending
China	Invention	Energy storage container	2021-12-29	Pending

3 SOLBANK 3.0 SYSTEM OVERVIEW

DNV reviewed product documentation pertaining to the technical specifications of the product. The review focuses on e-STORAGE's current product offerings, their core components and the secondary components that interact with those products at a higher level.

3.1 Product offerings

SolBank 3.0 is a utility-scale BESS with a rated capacity of 5.016 MWh and represents the third generation of e-STORAGE's proprietary storage product offering. It is a fully factory-integrated system featuring various components such as LFP cells, a BMS, and a liquid cooling thermal management system (see Figure 3-1). SolBank 3.0 utilizes 314 Ah battery cells and compact integration. It supports various PCS topologies, offers turn-key integration, and provides plug-and-play commissioning.

SolBank 3.0 offers two models: CSI-SolBank-S-5016-2h and CSI-SolBank-S-5016-4h. The 2-hour model has a rated DC capacity of 4,700 kWh, while the 4-hour model has a capacity of 4,800 kWh. Both models feature a battery voltage range of 1,164.8 V to 1,497.6 V, with a nominal voltage of 1,331.2 V. The nominal power for the 2-hour model is 2350 kW, and for the 4-hour model, it is 1,200 kW. The RTE at BOL is 93% for the 2-hour model and 94% for the 4-hour model. The dimensions of the ESS unit are 6,058 mm x 2,438 mm x 2,896 mm, and it weighs 43,000 kg. The system has an IP55 / NEMA 3R rating and operates in ambient temperatures ranging from -30 °C to 55 °C, with derating from 45 °C to 55 °C.



Figure 3-1 SolBank 3.0 with 5 MWh capacity

3.2 Product specifications

DNV reviewed SolBank 3.0's product data sheets [6] [7] and its specifications are presented in Table 3-1.

Table 3-1 SolBank 3.0 specifications

Parameter	Specifications	
	2-hour	4-hour
Model	CSI-SolBank-S-5016-2h	CSI-SolBank-S-5016-4h
Energy capacity	4,700 kWh	4,800 kWh
Battery capacity (BOL)	5,016 kWh	5,016 kWh
Rated DC capacity (BOL) @ FAT	4,700 kWh	4,800 kWh
Battery voltage range	1,164.8 V to 1,497.6 V	
Nominal voltage	1,331.2 V	
Nominal power	2,350 kW	1,200 kW
Rated current	2,400 A	1,200 A
Round-trip efficiency at BOL @ 25 °C	93%	94%
Dimensions of ESS unit (W×D×H)	6,058 mm x 2,438 mm x 2,896 mm	
Weight	43,000 kg	
Ingress protection (IP) rating	IP55 / NEMA 3R	
Salt spray protection	RAL9003 / C4 Coating	
Operating ambient temperature range (°C)	-30 °C to 55 °C (derating from 45 °C to 55 °C)	
Storage temperature range (°C)	-20 °C to 45 °C	-20 °C to 45 °C
Relative humidity	≤95% (non-condensing)	
Altitude	< 2,000 m (derating from 2,000 m to 4,000 m)	
Thermal management	Smart liquid cooling/heating	
Noise level @ 1m	≤75 dB(A)	
Auxiliary power interface	AC 480V / 60 Hz, 3P5W	
Auxiliary system peak power requirement @ -30 °C to 55 °C	39.33 kVA	22.66 kVA
Communication interfaces	Ethernet connection,	
Communication protocols	Modbus TCP/IP protocol	
Design life	≥ 20 Yrs	≥ 20 Yrs
Seismic rating	Zone 4	

A high-level wiring layout of SolBank 3.0, which shows main components such as battery pack, BMS box, thermal management system, and fire protection system, is presented in Figure 3-2.

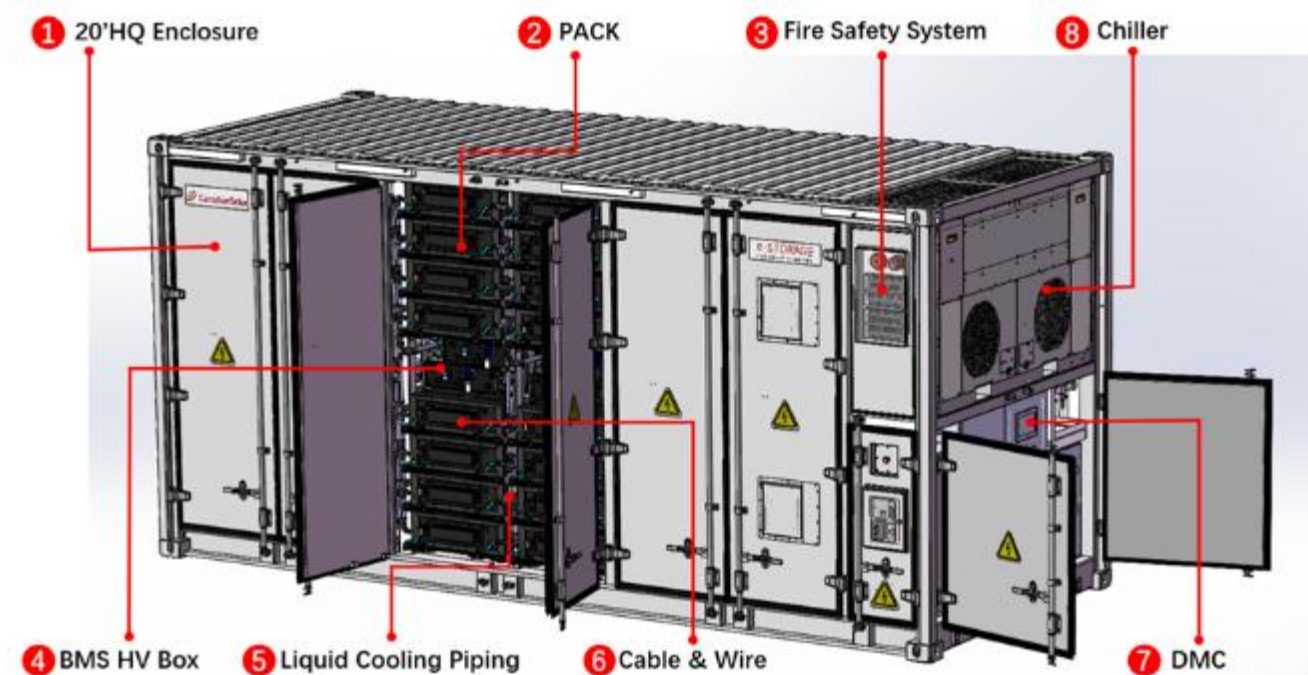


Figure 3-2 Layout and features of SolBank 3.0

DNV finds the SolBank 3.0 system specifications and design to be comparable to other similar products offered in the utility-scale BESS industry.

4 SOLBANK 3.0 PLUS SYSTEM OVERVIEW

SolBank 3.0 Plus, developed by e-STORAGE, is a utility-scale BESS designed for long-term energy storage. While this section references the Plus version, the focus of the review is specifically on SolBank 3.0. It is an enhanced version of SolBank 3.0, building upon its foundational design. With a nominal capacity of 5,016 kWh, SolBank 3.0 Plus is available in two configurations: 2-hour (S-PL-5016-2H) and 4-hour (S-PL-5016-4H) discharge durations. The system integrates LFP cells, specifically Cornex 314 Ah pre-lithiated cells. SolBank 3.0 claims up to 12,000 cycles for a 25-year design life. It operates in ambient temperatures ranging from -30 °C to 55 °C, with performance derating above 45 °C, and supports installation at altitudes up to 2,000 meters, with further derating up to 4,000 meters.

SolBank 3.0 Plus is housed in a 20 ft long cube container, measuring 6,058 mm × 2,438 mm × 2,896 mm and weighing 43,000 kg. It meets IP55/NEMA 3R ingress ratings, is coated with RAL9003/C4, and is rated for Seismic Zone 4. The system configuration includes 12 racks of 1P416S, each composed of 4 packs of 1P104S, and operates within a DC voltage range of 1,164.8 V to 1,497.6 V, with a nominal voltage of 1,331.2 V.

The SolBank 3.0 Plus product development timeline outlines a structured progression from initial announcement to full commercial readiness, see Figure 4-1. It begins in May 2025, with a formal press release and product unveiling at the Munich InterSolar event, marking the public introduction of the utility-scale BESS. By October 2026, SolBank 3.0 Plus is intended to become fully available for mass production and shipment, signaling its readiness for deployment at customer sites.

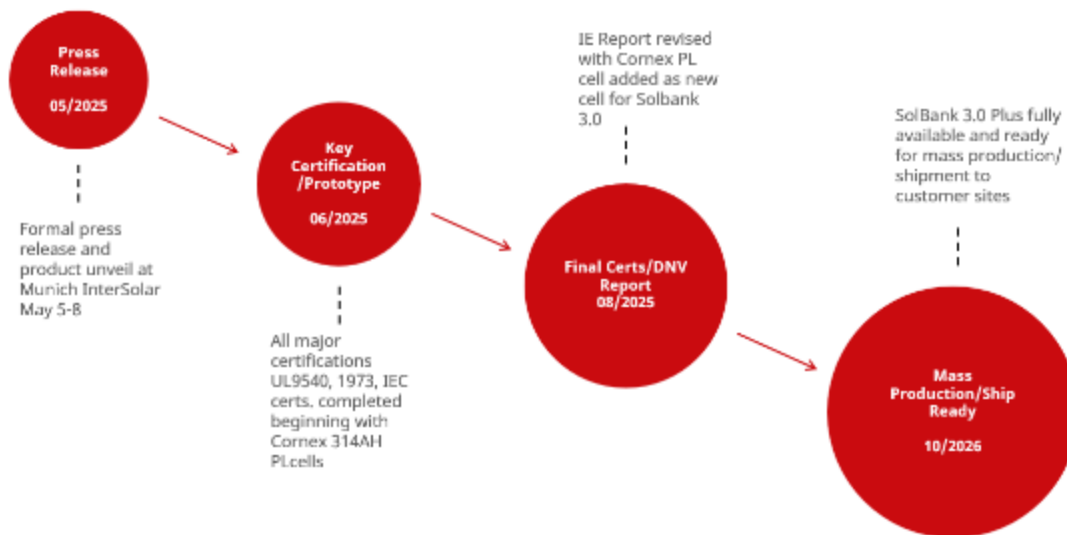


Figure 4-1SolBank 3.0 Plus development timeline

4.1 Product specifications

DNV reviewed SolBank 3.0 Plus product data sheets [8] [9] [10] and its specifications are presented in Table 3-1. DNV notes that the model number for both SolBank 3.0 and SolBank 3.0 Plus will remain the same.

Table 4-1 SolBank 3.0 Plus specifications

Parameter	Specifications	
	2-hour	4-hour
Model	CSI-SolBank-S-PL-5016-2h	CSI-SolBank-S-PL-5016-4h
Energy capacity	4,800 kWh	4,800 kWh
Battery capacity (BOL)	5,016 kWh	5,016 kWh
Rated DC capacity (BOL) @ FAT	4,800 kWh	4,800 kWh
Battery voltage range	1,164.8 V to 1,497.6 V	
Nominal voltage	1,331.2 V	
Nominal power	2,400 kW	1,200 kW
Rated current	2,400 A	1,200 A
Round-trip efficiency at BOL @ 25 °C	93%	94%
Dimensions of ESS unit (W×D×H)	6,058 mm x 2,438 mm x 2,896 mm	
Weight	43,000 kg	
Ingress protection (IP) rating	IP55 / NEMA 3R	
Salt spray protection	RAL9003 / C4 Coating	
Operating ambient temperature range (°C)	-30 °C to 55 °C (derating from 45 °C to 55 °C)	
Storage temperature range (°C)	-30 °C to 45 °C	-30 °C to 45 °C
Relative humidity	≤95% (non-condensing)	
Altitude	≤ 4,000 m (derating from 2,000 m to 4,000 m)	
Thermal management	Smart liquid cooling/heating	
Noise level @ 1m	≤75 dB(A)	
Auxiliary power interface	-AC 480V / 60 Hz, 3P5W	
Auxiliary system peak power requirement @ -30 °C to 55 °C	39.33 kVA	22.66 kVA
Communication interfaces	Ethernet connection,	
Communication protocols	Modbus TCP/IP protocol	
Design life	≥ 25 Yrs	≥ 25 Yrs
Seismic rating	Zone 4	

DNV has requested the rated current for SolBank 3.0 Plus and will include this information in the next iteration of the report.

5 BATTERY COMPONENT EVALUATION

This section outlines the battery and supporting auxiliary equipment, starting at the battery cell, and building up to the full dc side system specification.

5.1 Battery cell evaluation

SolBank 3.0 is integrated using modules and packs built with 314 Ah LFP prismatic cells and e-STORAGE offers the product with cells from multiple suppliers, such as:

- Hithium 314 Ah LFP cells (Please see Appendix A for Hithium cell information.)
- e-STORAGE 314 Ah LFP cells (Please see Appendix B for e-STORAGE cell information.)
- EVE 314 Ah LFP cells (Please see Appendix C for EVE cell information.)
- Cornex 314 Ah LFP cells (Please see Appendix D for Cornex cell information.)
- Sunwoda 314 Ah LFP cells (Please see Appendix E for Sunwoda cell information.)

5.2 Battery pack evaluation

e-STORAGE procures cells from various suppliers and integrates them into battery packs in its own manufacturing facilities. The battery pack leverages a 1P104S configuration with 104 cells connected in series. The SolBank 3.0 battery pack includes 35 more LFP prismatic cells compared to the SolBank 1.0 which enables the product to have higher energy ratings.

Figure 5-1 presents a detailed cross-sectional of the SolBank 3.0 battery pack. The cover, labelled HC420, provides protection and structural integrity to the pack. Below the cover, a gap filler is used to fill any gaps between components for thermal conductivity and preventing overheating. A pack level battery management system is located at the front side of the pack. At the bottom of the assembly is a liquid cooling plate made of Aluminum 3003 which dissipates heat from the battery cells through a liquid cooling thermal management system. Thermally conductive adhesives (or thermal glue) are used to ensure consistent temperature and reliable mechanical connection between the bottom part of the cells and the liquid cooling plate. This helps prevent the condensation of water within the battery pack, reducing the risk of fire hazards. The entire assembly is supported by a frame made of AISI304-Steel, and foam is used for insulation and cushioning.

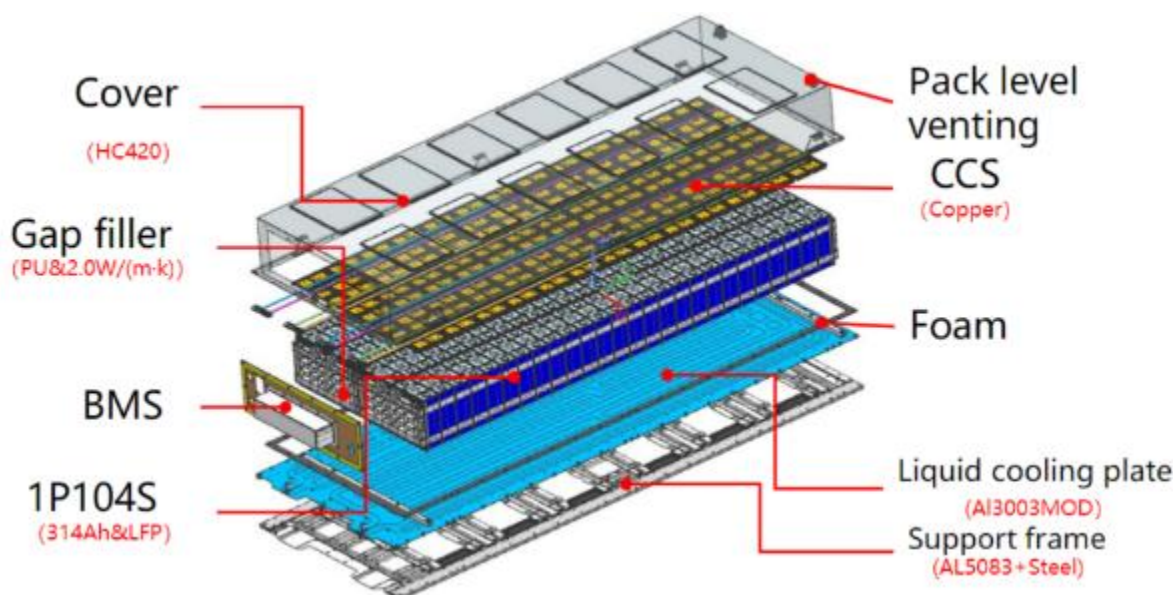


Figure 5-1 SolBank 3.0 battery pack layout

SolBank 3.0's battery pack specifications are presented in Table 5-1 [11].

Table 5-1 SolBank 3.0 battery pack specifications

Parameter	Specification	
Model	CSI-SolBank-P-104.5-2h-X ¹	CSI-SolBank-P-104.5-4h-X ¹
Configuration	1P104S	
Nominal energy	104.5 kWh	104.5 kWh
Operating voltage range	265.2 V to 374.4 V	
Nominal voltage	332.8 V	
Maximum continuous power	52 kW	26 kW
Maximum continuous current	240 A	120 A
Peak power	52 kW	26 kW
Optimal operating temperature range (Charge)	0 °C to 55 °C	0 °C to 55 °C
Optimal operating temperature range (Discharge)	0 °C to 55 °C	0 °C to 55 °C
Storage temperature	Air-conditioned storage, 10 °C ~ 30 °C, humidity <90%	
Dimensions (W x L x H)	790 mm ± 3 mm × 2,180 mm ± 5 mm × 248 mm ± 5 mm	
Weight	670 kg ± 15 kg	
Energy density	155.97 Wh/kg	
Ingress protection rating	IP67	

The battery pack specifications generally align with expectations. DNV does note that the battery pack features an ingress protection rating of IP67, where the first digit (6) indicates no dust ingress while the second digit (7) indicates protection

¹ DNV notes that the model numbers listed in Table 5-1 are generic. The actual models are based on different cell types and have specific model numbers.

against water ingress for short periods of immersion in water up to 1m in depth. DNV finds this level of protection to be aligned with industry best practices. DNV also notes that the battery pack should be stored in temperature controlled conditions, as specified in Table 5-1.

5.3 Battery string evaluation

According to e-STORAGE's documentation, a "rack" refers to a unit composed of four battery packs. DNV notes that in some configurations, two strings stacked together may also be considered a rack. There is a total of 12 strings or 48 packs per enclosure. SolBank 3.0's battery string specifications are presented in Table 5-2.

Table 5-2 SolBank 3.0 battery string specifications

Parameter	Specification	
Model	CSI-SolBank-R-418-2h-X ³	CSI-SolBank-R-418-4h-X ³
Configuration	1P4S (4 packs per string)	
Maximum Continuous power	208 kW	104 kW
Peak Power	208 kW	104 kW
Maximum Continuous current	240 A	120 A
Rated charge/discharge power	208 kW continuous power to cell max 3.6 V	104 kW continuous power to cell max 3.6 V
Rated energy	418.0 kWh	
Operating voltage range	1,060.8 V to 1,497.6 V	
Nominal voltage	1,331.2 V	
Operating temperature range (charge)	0 °C to 55 °C	
Operating temperature range (discharge)	0 °C to 55 °C	
Storage temperature	-20 °C to 45 °C, humidity < 90%	
Dimensions (W x L x H)	Pack: 790 mm ± 3 mm × 2,180 mm ± 5 mm × 248 mm ± 5 mm Control box: 600.0 mm ± 1.0 mm x 600.0 mm ± 1.0 mm x 170.0 mm ± 0.5 mm	
Weight	Pack: 670 kg ± 15 kg Control box: 31.4 kg	
Energy Density (Wh/kg)	152 Wh/kg	
Thermal management strategy	Liquid cooling and liquid heating for cell	
Ingress protection rating	IP20	

The SolBank 3.0 battery string, available in two models, features a 1P4S configuration where four packs are connected in series. It offers a maximum continuous power of 208 kW (2 hour) or 104 kW (4 hour) and a rated energy capacity of 418.0 kWh. The operating voltage ranges from 1060.8 V to 1497.6 V, with a nominal voltage of 1331.2 V. It operates within a temperature range of 0 °C to 55 °C and includes liquid cooling and heating for thermal management. The ingress protection rating is IP20.

DNV considers these specifications to align well with similar products in the market.

³ DNV notes that the model numbers listed in Table 5-2 are generic. The actual models are based on different cell types and have specific model numbers.

5.4 Operational evaluation

Operational evaluation of a BESS is essential to ensure their effective and efficient functionality. This involves monitoring and analyzing the performance of the system, such as the battery capacity, efficiency, response time, and power output.

e-STORAGE informed DNV that it conducts thorough due diligence to ensure new battery cells meet all safety and performance requirements. This process includes comprehensive reviews and internal testing in e-STORAGE's labs before any new cells are approved for use in the SolBank product lines. Once integrated into its supply chain, e-STORAGE guarantees consistent specifications at the ESS level, including capacity, degradation, and round-trip efficiency.

The SolBank 3.0 performance guarantee includes capacity, degradation, RTE, and availability, all managed under e-STORAGE's BESS LTSAs. The degradation curve and other performance guarantees are complex and depend on specific project applications and conditions. This complexity arises because the degradation curve cannot be validated through real-time testing at the SolBank 3.0 level, such as operating a SolBank 3.0 for 20 years. For more detailed information, refer to Section 8 herein for details. DNV only reviewed the performance of the Hithium-based SolBank 3.0. See cell level performance data for Hithium cell is detailed in Appendix A herein.

Round-trip efficiency is a measure of the efficiency of a storage system, indicating how much energy is retained after a cycle of charging and discharging compared to the energy initially inputted. RTE is crucial as it directly impacts the economic and operational viability of energy storage systems; higher RTE means less energy is lost to inefficiencies, thereby enhancing the overall performance and cost-effectiveness of the system.

Table 5-3 presents data on the round-trip efficiency of SolBank 3.0 under specific conditions, including a charge/discharge power rating of 2350 kW at temperature of 25 °C at BOL [12]. The DC charged energy ranges from 5.3624 MWh to 5.3703 MWh, while the DC discharged energy ranges from 5.0556 MWh to 5.083 MWh. The values indicate RTE consistency, with the highest efficiency recorded at 94.71% and the lowest at 93.49%. These values reflect the battery's ability to retain energy during its operation, showing relatively high efficiency across the tested samples.

Table 5-3 DC RTE

No	DC charged energy (MWh)	DC discharged energy (MWh)	DC RTE
1	5.4120	5.0595	93.49%
2	5.3624	5.0667	94.49%
3	5.3626	5.0556	94.28%
4	5.3660	5.0822	94.71%
5	5.3703	5.083	94.65%

DNV has requested confirmation on whether the RTE aligns with the guarantee provided by e-STORAGE. Additionally, DNV has asked for long-term, system-level degradation data for SolBank 3.0, as well as operational system-level data for all cell variants. This information will be included in the report once it becomes available.

5.5 THERMAL MANAGEMENT SYSTEM

DNV has reviewed the following documents provided by e-STORAGE related to the Thermal Management System (TMS) of SolBank 3.0: [13], [14], [15], [16], [17], [18], [19], [20], [21], [22], [23], [24], [25], [26]

5.5.1 TMS summary

Table 5-4 summarizes the key points from thermal management system analysis. Thorough commentary follows in the remaining sections Section 5.5 herein.

Table 5-4 Key TMS findings

Item	DNV opinion	Comments
TMS design	Meets expectations	Typical of liquid-cooled BESS
Thermal performance - cell maximum temperature	Meets expectations	Only Hithium cell performance reviewed. The testing data did not specify ambient temperature conditions.
Thermal performance - cell temperature variation	Low risk	Only Hithium cell performance reviewed. Low technical risk for uneven cell aging across the BESS.
TMS equipment maintenance - prescribed scope	Meets expectations	Thorough chiller maintenance checklist
TMS equipment maintenance - frequency of inspection/service	Meets expectations	Typical for outdoor commercial cooling equipment and appropriate to reduce risk for early equipment failure

5.5.2 System overview

e-STORAGE provides a liquid cooled design for the thermal management of SolBank 3.0. Figure 5-2 represents the SolBank 3.0 thermal management system design and components. The simple schematic is for reference to demonstrate heat flow paths. It highlights the primary heating and cooling components leveraged for maintaining optimal thermal conditions for BESS. Coolant is pumped from the modules to a mechanical refrigeration heat exchanger, a dry-cooler radiator, or electric heater depending on the call for heating or cooling from the modules and the exterior ambient temperature. In cooling mode, the primary cooling method is to pump coolant through a heat exchanger connected to a mechanical refrigeration circuit. This method provides cooling at the highest ambient temperatures SolBank 3.0 can operate in. However, when the ambient temperature drops below 10 °C, a portion of the coolant flow will also be routed directly to the dry cooler which provides compressor-less cooling capacity. Once the ambient temperature drops below -10 °C, the BESS entire cooling requirements can be satisfied via the dry cooler allowing the compressor to fully shut down. This cooling cycle (called an economizer) provides significant auxiliary energy savings, which DNV finds favorable. Providing economizer cooling is an industry leading feature.

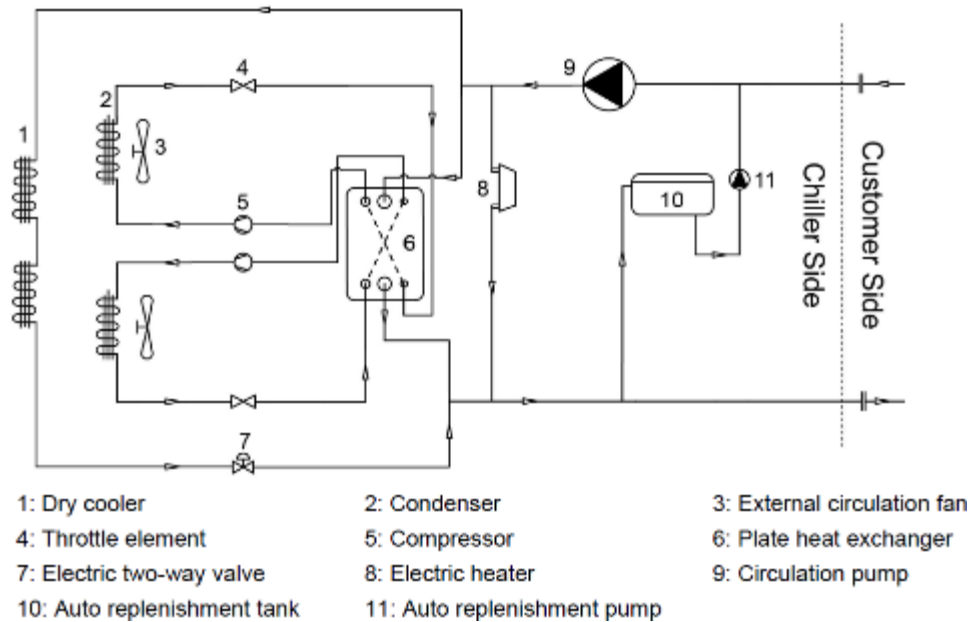


Figure 5-2 Overall thermal management system schematic of SolBank 3.0

Figure 5-3 provides a detailed view of SolBank 3.0 battery pack (see Figure 5-1 for overall layout), whereas separate components are highlighted: the heat transfer plate, with a thickness of 1.2 mm; and the runner plate, also 1.2 mm thick.

DNV considers the design to be in line with similar industry products.

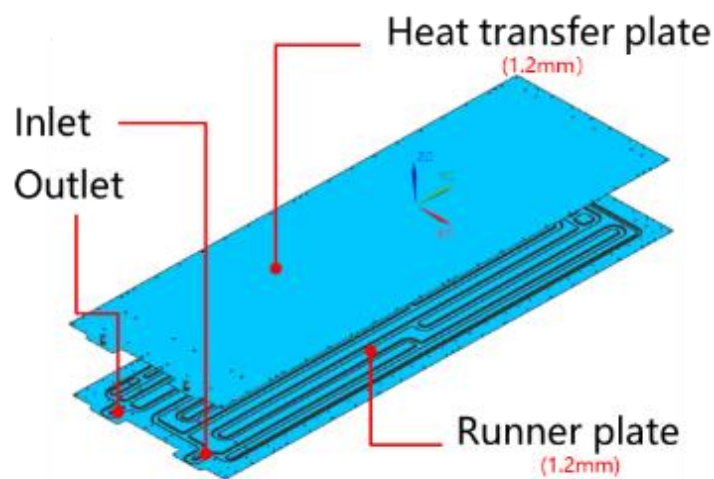


Figure 5-3 Battery pack and cold plate diagram

DNV notes all liquid-cooling systems present inherent risks of introducing a conductive fluid near the batteries and electronics. The risk can range from general electronics failure to battery thermal runaway. The specification sheet indicates

an IP26 rating for the entire chiller and IP67 for the electrical parts [15] [27]. DNV has reviewed the ingress protection reports for the chiller [28] [29].

DNV has reviewed the SolBank 3.0 Leakage Management Design Description V1.0 [24]. The chiller contains a liquid level gauge for monitoring liquid capacity, triggering a low liquid level alarm when needed. Information is synchronized to the BMS and EMS. The chiller will monitor for potential leakage related faults during operation including low water tank level, incorrect pressure difference between inlet and outlet. The bottom of the container includes two liquid discharge floor drains, each with a diameter of 37 mm to minimize impact to the system in the event of a leakage. Document [24] also contains a pipe certification test conducted by VOSS which DNV views favorably.

For cooling non-battery BESS electrical components, SolBank 3.0 utilizes the Envicool EC06HDNC1U, which is a compact, high-efficiency air conditioner designed specifically for outdoor cabinets. It operates on a 230 VAC power input and provides a cooling capacity of 600 W at L35/L35 conditions. The unit is door-mounted, facilitating easy integration into outdoor cabinets. It comes standard with a heater and can operate within a wide temperature range of -40 °C to 55 °C, making it suitable for various environmental conditions. The EC06HDNC1U is UL certified using R513A refrigerant and complying with RoHS standards. DNV notes that the unit uses R513A refrigerant, which requires careful handling and disposal to avoid environmental harm. It has a lifespan of over 10 years and the unit is resistant to corrosive environments, having been tested for IP55 protection and salt fog resistance. DNV considers the unit air conditioner's energy efficiency ratio (EER) to be in line with similar products in industry.

5.5.3 Thermal parameters and HVAC capacity

Table 5-5 lists the thermal parameters for SolBank 3.0. These temperatures are the target ranges which the thermal management system seeks to maintain within the BESS. The cell temperature optimal range is the primary evaluation criterion DNV reviews for thermal performance.

Table 5-5 Product temperature criteria

Parameter	Temperature Values	Comments
BESS operational range	-30 °C to 55 °C	External ambient temperature
Cell operational range	Hithium: 0 °C to 60 °C (Charge) -30 °C to 60 °C (Discharge)	
Cell optimal range	Hithium: 25 °C	Same for charge and discharge
Cell warranty range	Not Available	

DNV finds this target optimal range to be typical within the industry to maximize performance.

DNV reviewed performance guarantee (see Section 8.2.1 herein) for the product and found to be in line with similar products in industry. DNV reviewed acoustic and noise measurement test reports and found them to be in line with industry expectations [26] [30] [31].

The chiller is designed to manage the thermal loads of the batteries/cabinet/BESS. SolBank 3.0 provides a different size chiller for the 2-hour model vs the 4-hour model. DNV finds this 'right-sizing' of the equipment favorable because the cooling needs of a 0.5C system are often double that of a 0.25C system. For each chiller size, e-STORAGE has (via two independent vendors) two chiller configurations available. Figure 5-4 shows first- and second-generation chiller

configurations for 4-hour chillers. The 2-hour chillers (not shown) are similar to the 4-hour chillers configurations, but with one additional fan for each generation version. It is unclear to DNV what scenarios, or within which BESS models, the first-generation chiller would be implemented instead of the second-generation chiller. The capacities and specifications for both models of the BESS are shown in Table 5-6, which is applicable to both configuration generations and both vendors.

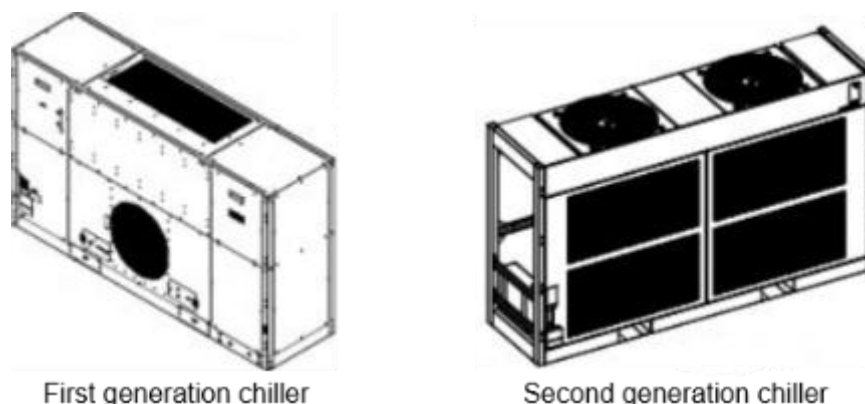


Figure 5-4 Two styles of chiller for 0.25C SolBank 3.0

Table 5-6 Chiller specifications

Element	4-hour SolBank 3.0	2-hour SolBank 3.0	Comment
Refrigerant	R513A		
Operating ambient temp	-30 °C to 55 °C		
Cooling capacity	25 kW	60 kW	@45 °C ambient temperature and 20 °C coolant supply temperature
Cooling power consumption	12.5 kW	30 kW	@45 °C ambient temperature and 20 °C coolant supply temperature
Heating capacity	16 kW to 19 kW	16 kW to 19 kW	Exact value depends on OEM supplier
Coolant flow rate	240 L/min @60 kPa	500 L/min @130 to 140 kPa	
Noise level	≤ 75 dBA		

DNV reviewed analytical calculations of design for internal and external loads to be managed by the chiller [32]. The chiller capacity meets DNV's expectations as a sizing choice for the static cooling loads reviewed. This is a simplified analytical engineering check focused on the equipment and BESS specifications, which does not account for dynamic operation and the resulting temperatures within packs and cells.

DNV notes the chillers' sound power ratings align with the containerized BESS noise performance (see Table 3-1) and is within the expected range for cooling equipment of this size.

DNV has not reviewed the cooling airflow clearance requirements, however, has received e-STORAGE confirmation that the required clearance distance from the chiller condenser coil is smaller than the distance being used at the system level.

5.5.4 Thermal performance

The thermal performance of the e-STORAGE may vary from one battery cell supplier to the next because the unique characteristics of each LFP model are the primary factor in the BESS cooling load magnitude. Thus, in this report, thermal performance is reviewed separately for each cell supplier in the Appendices. DNV has only reviewed the thermal using the Hithium cell, see Appendix A.4 herein.

5.5.5 Maintenance and expected life

e-STORAGE provided user manuals for the 25 kW (model BTM250-ESB) and 60 kW (model BTMS-600-ES) energy storage liquid cooling chiller units. The manuals provide detailed information on the product's overview, installation, control operation, routine maintenance, and troubleshooting [33] [34]. This manual is primarily for installation engineers, technical support engineers, and after-sales engineers, and includes safety precautions, product descriptions, installation instructions, control operations, system priming and rehydration, routine maintenance, and troubleshooting.

The safety precautions section emphasizes the importance of adhering to safety regulations and provides warnings about potential hazards that could result in personal injury or equipment damage. It covers general safety, electrical safety, operational safety, application security, and EMC considerations.

The installation instructions section includes notes on ensuring the outer packaging is intact during transportation and handling, maintaining good air circulation space to prevent hot air from flowing back to the air inlet, and avoiding installing multiple chillers back-to-back to prevent airflow interference. It also covers installation preparation, mechanical installation, and electrical connections, emphasizing that electrical connections must be performed by trained professionals and that the chiller must be reliably grounded before connecting to the power supply.

The system priming and rehydration section provides detailed steps for preparation before debugging, system pressure maintenance, vacuuming, and filling. It emphasizes the importance of ensuring the inlet and outlet pipe connections are tightened and that the connection of power and communication cables is complete.

The routine maintenance section outlines regular cleaning and maintenance to ensure the chiller operates efficiently. It includes instructions for unit cleaning and maintenance, fan and condenser maintenance, and antifreeze maintenance, recommending regular checks and replacements as necessary. The maintenance schedule provides a recommended maintenance schedule, including weekly, monthly, quarterly, semi-annual, annual, and biennial tasks. Key maintenance activities include spot checks for secure installation and absence of corrosion, inspection of high and low voltage harness connections, checking electronic components, condenser fans, PTC heaters, and overall unit operation, cleaning filters and condensers, inspecting coolant levels, and replacing coolant every two years.

The replenish coolant operation section outlines steps for replenishing coolant when levels are low or an alarm occurs, including opening the coolant filling cover, opening the exhaust valve of the auxiliary coolant reservoir, filling the antifreeze from the auxiliary water filling tank, and filling until the liquid level reaches the highest level line.

Other important notes include not operating the unit without antifreeze in the waterway, ensuring the main power supply has a wire diameter of more than 7AWG, maintaining the working voltage between AC323V and AC552V, equipping the main power supply with overcurrent and leakage current protection devices, avoiding operating the unit while submerged in water, not touching the unit while it is running, preventing the unit from being squeezed by heavy objects, only allowing professionals to disassemble the unit, cleaning the condenser and air inlets/outlets every three months, and replacing the coolant every two years.

In addition, the troubleshooting section provides detailed instructions for handling fault alarms and troubleshooting common issues such as fan failures, refrigeration system failures, and coolant circulation system failures. It also includes steps for replacing key components like the condenser fan, compressor, electric heater, and circulating water pump.

DNV considers the manual to be similar industrial products and sufficient for providing the preventative maintenance.

5.6 Battery management system review

The primary objective of the BMS is to ensure safe, reliable and efficient operation of BESS under different conditions by monitoring, protecting, optimizing and controlling. Accordingly, DNV's assessment framework is designed to leverage industry's best practices and use them as benchmarks for evaluation. The framework aims to achieve the following objectives:

1. Evaluating the modularity and scalability of the design in terms of redundancy, communication, and separation of safety critical components.
2. Assessing the BMS ability to detect and appropriately respond to abnormal or unsafe conditions and to safeguard life and assets.
3. Evaluating the balancing function and its ability to maintain uniform voltage and SOC across the cells.
4. Assessing the BMS's ground fault protection device to ensure isolation between BESS and the ground is detectable and responses are appropriate under normal and abnormal operating conditions.
5. Assessing the precharge circuit and logics and its ability to limit in rush current to the PCS and fail safe under abnormal conditions.
6. Evaluating BMS firmware functional safety design complies industry norm and relevant codes and standards.

Based on the information provided, DNV to considers the e-STORAGE's BMS to be in line with similar products in the same class. However, information related to software functional safety was unavailable and will be reviewed in subsequent versions.

5.6.1 BMS architecture

SolBank 3.0's BMS leverages a three-level architecture, including a battery management unit (BMU) at the module level, the battery pack control unit/battery cluster (pack) control unit (BCM) at the cluster level and SolBank Controller at the enclosure (system level).

The BMU collects the cells' voltage, temperature collection, and executes balancing. The BMU communicates the cell level information to the BCM using either isolated Serial Peripheral Interface (isoSPI) or Controller Area Network (CAN) communication. The BCM collects the total voltage and current of the battery cluster, controls the battery pack contactor, and communicates with the SolBank Controller. It also estimates state of charge (SOC) and state of health (SOH), calculates charge/discharge current limit, and processes faults and alarms.

The SolBank Controller processes the battery information uploaded by the BCM, has a human machine interface (HMI) for parameter setting, handles fault alarm and data recording, collects sensor information in the container, exchanges information with air conditioners, and communicates with BCI (which is not part of SolBank 3.0's offering) and energy management system (EMS) using the Modbus TCP protocol [35]. The schematic diagram is shown in Figure 5-5.

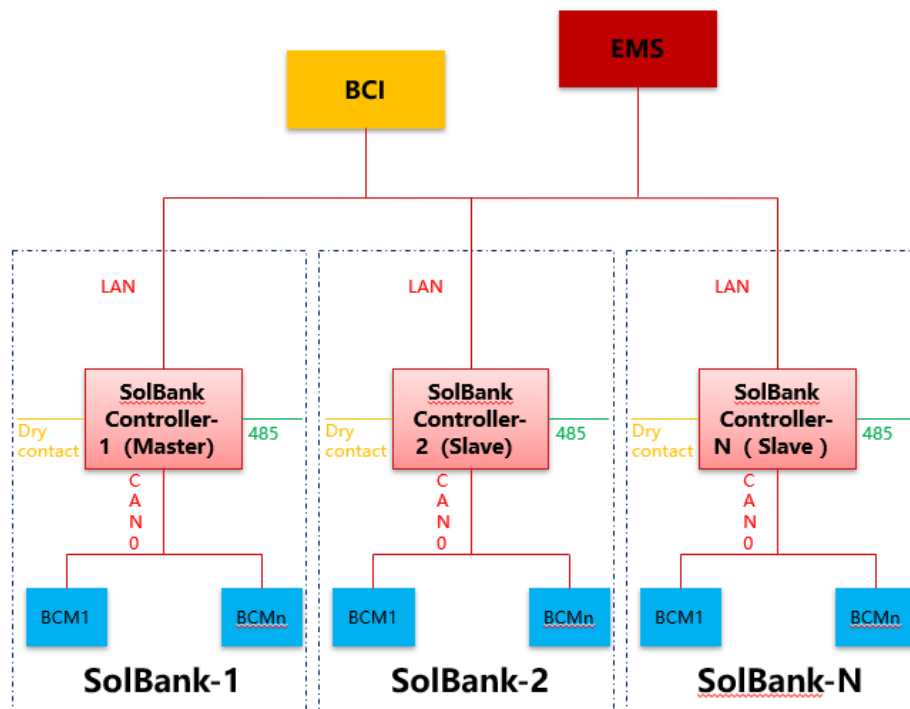


Figure 5-5 BMS architecture

The SolBank Controller has Master-Slave configuration. Master controller aggregates slave controllers' container-level data. For example, deviation in voltage among different units requires assessment to establish dc-side grid connection. The master controller collects all cluster voltages (both its own and slaves') to perform this assessment and determine whether grid connection is allowed. In addition, master controller consolidates slave controllers' data to provide an interface with BCI communication. SolBank Controller-1 (Master) serves as the host, retrieving control-level data from SolBank Controller-2, and N units via the LAN protocol, see Figure 5-5. It aggregates and processes this data and acts as the primary interface for communication with the BCI.

Table 5-7 summarizes the details of BMS parameter monitoring.

Table 5-7 Summary of BMS parameter monitoring

Parameter	Sampling error	Sampling cycle	Sampling range	Comment
Cell voltage	± 5 mV	50 ms	2.0 V to 4.5 V	104 voltage sensors per pack, 1 per cell
Temperature	± 2 °C	200 ms	-30 °C to 125 °C	56 temperature sensors per pack
Rack voltage	$\pm 0.2\%$	50 ms	0 V to 1500 V	416 voltage sensors per rack
Rack current	$\pm 0.2\%$	50 ms	-300 A to 300 A	1 current sensor per rack

DNV finds the BMS design to be standard.

DNV has reviewed BMU inspection report [36], which appears to have test results for voltage sampling performance, temperature sampling performance, high temperature operation, overvoltage, thermal test, and fast transient electrical Surge

interference resistance tests. The report supports the cell voltage and temperature sampling error values provided in Table 5-7.

5.6.2 Protective functions

The BMS system sets a series of alarms that are designed to provide a multi-level alarm/warning system in the event of any faults or conditions which may indicate abnormal behavior, or a precursor to such behavior. For example, the BMS monitors cell, module, and rack parameters such as current, voltage, and temperature for immediate safety conditions or conditions that may affect the battery's long-term performance and warranty.

DNV considers SolBank 3.0's BMS list of alarms and warnings to be comprehensive and can provide typical protective functions. Table 5-8 shows the BMS alarms and warnings [37], [38], [39]. For each parameter, there are three levels of alarms. Level 1 denotes an alert level. Level 2 and 3 denote a warning and critical levels, respectively. For level 1, control system action reports alert to the alarm. For level 2, the control system acts to prohibit charge or discharge, and for level 3, contactor is disconnected, see Figure 5-6 [40].

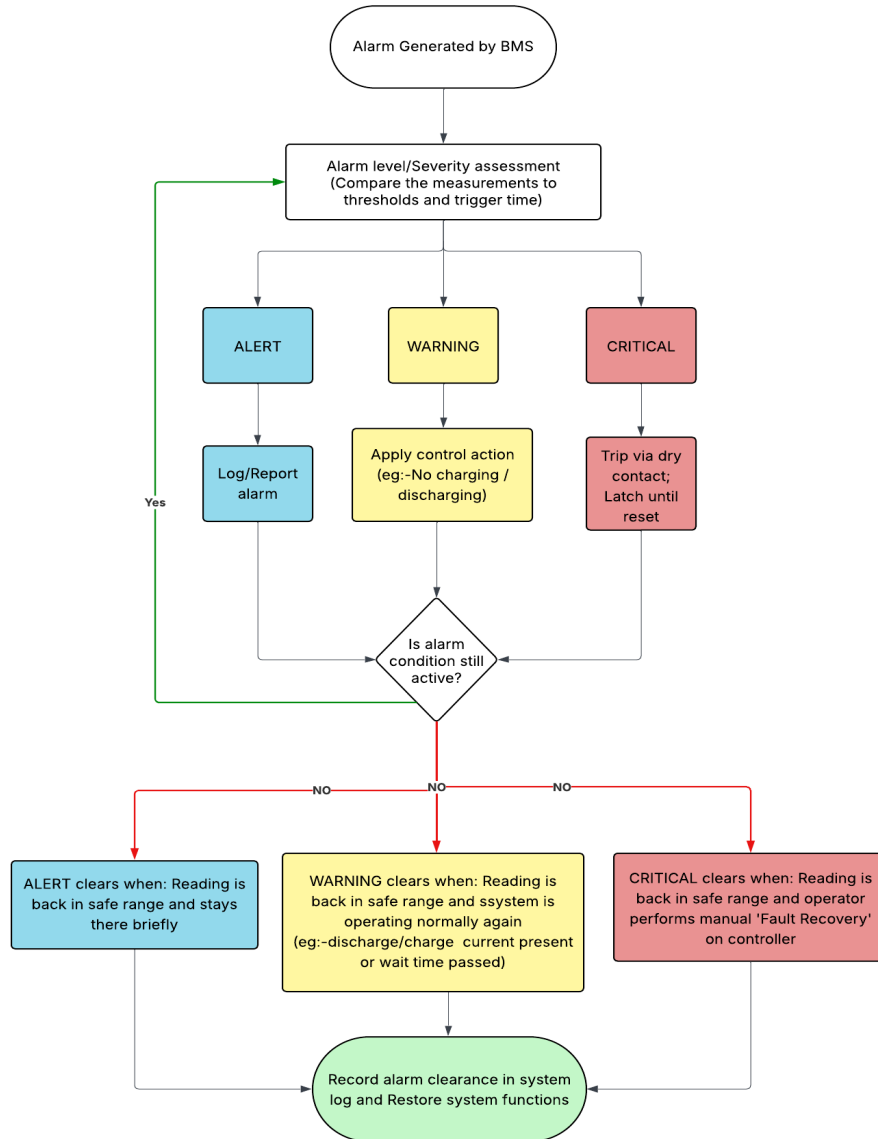


Figure 5-6 BMS Alarm Handling Process Flowchart

DNV has compared Table 5-8 parameters against specifications provided in Appendices A.2, B.2, C.2, D.2, E.2, and Table 5-1. Generally, DNV finds the parameters logical and in line with the specifications mentioned.

Table 5-8 List of fault and alarms and respective levels

Item	Alarm level	Alarm trigger threshold	Trigger duration	System control action	Regression value	Clearing condition	
						Alarm clearing condition	No charging and discharging faults clearing condition
Cell high voltage	Alert	3.55 V	3 s	Report to the alarm	0.2 V	Alarm triggering threshold – Regression value	Not provided
	Warning	3.6 V	3 s	No charging; Allow discharging		Alarm triggering threshold – Regression value	Alarm clear and (All clusters have discharge current or the average voltage of current cluster cells is less than 3.3 V)
	Critical	3.65 V	3 s	Output dry point, delay 3s disconnect contactor		Alarm triggering threshold – Regression value	SolBank Controller click “Fault recovery”
Cell low voltage	Alert	2.9 V	3 s	Report to the alarm	0.2 V	Alarm triggering threshold + Regression value	Not provided
	Warning	2.8 V	3 s	No discharging; Allow charging		Alarm triggering threshold + Regression value	Alarm clear and all clusters have charging current
	Critical	2.55 V	3 s	Output dry point, delay 3s disconnect contactor		Alarm triggering threshold + Regression value	SolBank Controller click “Fault recovery”
Cell voltage difference	Alert	300 mV	3 s	Report to the alarm	50 mV	Alarm triggering threshold – Regression value	Not provided
	Warning	400 mV	3 s	No charging; Prohibited discharge		Alarm triggering threshold – Regression value	Alarm clear and delay 30 min
	Critical	600 mV	3 s	Output dry point, delay 3s disconnect contactor		Alarm triggering threshold – Regression value	SolBank Controller click “Fault recovery”
Battery high temperature	Alert	40°C	3 s	Report to the alarm	10°C	Alarm triggering threshold – Regression value	Not provided
	Warning	55°C	3 s	No charging; Prohibited discharge	25°C	Alarm triggering threshold – Regression value	Alarm clear
	Critical	58°C	3 s	Output dry point, delay 3s disconnect contactor	28°C	Alarm triggering threshold – Regression value	SolBank Controller click “Fault recovery”
Battery low temperature	Alert	10°C	3 s	Report to the alarm	5°C	Alarm triggering threshold + Regression value	Not provided
	Warning	5°C	3 s	No charging; Prohibited discharge	8°C	Alarm triggering threshold + Regression value	Alarm clear
	Critical	0°C	3 s	Output dry point, delay 3s disconnect contactor	13°C	Alarm triggering threshold + Regression value	SolBank Controller click “Fault recovery”
Battery temperature difference	Alert	10°C	3 s	Report to the alarm	5°C	Alarm triggering threshold – Regression value	Not provided

Item	Alarm level	Alarm trigger threshold	Trigger duration	System control action	Regression value	Clearing condition	
						Alarm clearing condition	No charging and discharging faults clearing condition
	Warning	15°C	3 s	No charging; Prohibited discharge		Alarm triggering threshold – Regression value	Alarm clear
	Critical	20°C	3 s	Output dry point, delay 3s disconnect contactor		Alarm triggering threshold – Regression value	SolBank Controller click "Fault recovery"
Low SOC	Alert	5%	3 s	Report to the alarm	2%	Alarm triggering threshold + Regression value	Not provided
Total voltage too high	Alert	3.55 V*416	3 s	Report to the alarm	10 V s	Alarm triggering threshold – Regression value	Not provided
	Warning	3.6 V*416	3 s	No charging; Allow discharging		Alarm triggering threshold – Regression value	Alarm clear and (All clusters have discharge currents)
	Critical	3.65 V*416	3 s	Output dry point, delay 3s disconnect contactor		Alarm triggering threshold – Regression value	SolBank Controller click "Fault recovery"
Total voltage too low	Alert	2.9 V*416	3 s	Report to the alarm	10 V	Alarm triggering threshold + Regression value	Not provided
	Warning	2.8 V*416	3 s	No discharging; Allow charging		Alarm triggering threshold + Regression value	Alarm clear and (All clusters have charge currents)
	Critical	2.55 V*416	3 s	Output dry point, delay 3s disconnect contactor		Alarm triggering threshold + Regression value	SolBank Controller click "Fault recovery"
High-voltage connector overtemperature	Alert	100°C	3 s	Report to the alarm	5°C	Alarm triggering threshold – Regression value	Not provided
	Warning	105°C	3 s	No charging; Prohibited discharge		Alarm triggering threshold – Regression value	Alarm clear
	Critical	110°C	3 s	Output dry point, delay 3s disconnect contactor		Alarm triggering threshold – Regression value	SolBank Controller click "Fault recovery"
Overcharging current	Alert	110 A (0.25P) 230 A (0.5P)	3 s	Report to the alarm	10 A	Alarm triggering threshold – Regression value	Not provided
	Warning	120 A (0.25) 240 A (0.5P)	3 s	No charging; Prohibited discharge		Alarm triggering threshold – Regression value	Alarm clear and (Delay by 30 minutes or all clusters have discharge currents)
	Critical	130 A (0.25) 250 A (0.5P)	3 s	Output dry point, delay 3s disconnect contactor		Alarm triggering threshold – Regression value	SolBank Controller click "Fault recovery"
Over discharging current	Alert	110 A (0.25P) 230 A (0.5P)	3 s	Report to the alarm	10 A	Alarm triggering threshold – Regression value	Not provided
	Warning	120 A (0.25) 240 A (0.5P)	3 s	No discharging; Allow charging		Alarm triggering threshold – Regression value	Alarm clear and (Delay by 30 minutes or all clusters have charge currents)

Item	Alarm level	Alarm trigger threshold	Trigger duration	System control action	Regression value	Clearing condition	
						Alarm clearing condition	No charging and discharging faults clearing condition
	Critical	130 A (0.25) 250 A (0.5P)	3 s	Output dry point, delay 3s disconnect contactor		Alarm triggering threshold – Regression value	SolBank Controller click "Fault recovery"
Low insulation resistance (k Ω)	Alert	2000	60 s	Report to the alarm	10 k Ω	Alarm triggering threshold + Regression value	Not provided
	Warning	1500	60 s	No charging; Prohibited discharge		Alarm triggering threshold + Regression value	Alarm clear
	Critical	750	60 s	Output dry point, delay 3s disconnect contactor		Alarm triggering threshold + Regression value	SolBank Controller click "Fault recovery"
Local EMS communication failures	Warning	Not provided	3 s	No charging; Prohibited discharge	Not provided	Communication recovery	Alarm clear
BMU communication failures	Critical	Not provided	3 s	Output dry point, delay 3s disconnect contactor	Not provided	Communication recovery	SolBank Controller click "Fault recovery"
Display control: fire fighting fault / emergency stop signal / Electric operation / fuse disconnected	Critical	Not provided	2 s	Output dry point, delay 3s disconnect contactor	Not provided	Real-time monitor	SolBank Controller click "Fault recovery"
Cell voltage acquisition fault	Critical	Not provided	3 s	Output dry point, delay 3s disconnect contactor	Not provided	Data sampling recovery	SolBank Controller click "Fault recovery"
Monomer temperature acquisition fault	Critical	Number of invalid temperatures ≥ 4 or Number of slave controls of invalid temperature ≥ 3	3 s	Output dry point, delay 3s disconnect contactor	Not provided	Data sampling recovery	SolBank Controller click "Fault recovery"

DNV finds the list of alarms and warnings to be comprehensive. However, certain items appear to be misaligned with the specifications and require further clarification from e-Storage, as outlined in the bullet points below.

- Battery high temperature's critical alarm trigger is set to 58 °C, which appears to be outside of the maximum operation temperature of the battery pack defined in Table 5-1 (0 °C to 55 °C for charge and discharge operations). DNV also notes that the cell's optimal operating temperature can range from 15 °C to 45 °C and its maximum operating temperature can range from 0 °C to 55 °C, See Table D.2 herein. In response to DNV observation, e-STORAGE stated that the optimal temperature range is influenced by cell-specific characteristics. Also, e-

STORAGE stated that generally, events where cells exceed 55 °C are rare and if they occur, charging and discharging will be prohibited and BMS will enter the protection logic that requires a fault recovery procedure.

- Low SOC appears to have only alert level alarm. CSI stated that the reason behind this is that the control system does not allow estimated SOC to participate directly in power control.
- Overcharging/overdischarging current critical parameters appear to violate the pack's maximum current provided in the battery pack specifications. CSI stated that critical range exceeds the maximum values provided in the specification. DNV did not receive information that defined the critical range values.
- Local EMS communication failures appear to only raise warning. It is not clear if loss of communication allows the system to hold the last setpoint command for any period of time or transition to different modes of operation before blocking the charge and discharge operation. CSI stated that the loss of communication failure here is between SolBank Controller and BCM, where SolBank Controller will report prohibit charging and discharging.

5.6.3 State of charge and state of health estimation

SOC estimation allows for real-time determination of the available capacity of the battery, enabling efficient energy management and preventing overcharging or over-discharging, which can degrade battery performance and reduce capacity. SOH estimation provides insights into the battery's aging and available capacity, enabling timely maintenance, augmentation, and more accurate energy availability predictions and planning. Together, these metrics enhance battery reliability, availability, performance, and safe operation.

DNV considers the SOC estimation accuracy to be in line with similar products in the industry, which was estimated to have a 3% margin of error. The SOH estimation method appears to only capture linear characteristics of the system, which DNV considers to be in line with similar products in the industry.

The SolBank 3.0 BMS's SOC estimation is based on the current integration method, supplemented by open circuit voltage (OCV) calibration [41]. The SOC is reset to 100% or 0% when the cell voltage reaches the secondary protection value of single overvoltage during charging, or it reaches the secondary protection value of the single undervoltage. In addition to current integration and OCV calibration, the following strategies can be used to improve SOC accuracy under various conditions:

- Rate and temperature correction functions are added to the SOC model based on extensive battery characteristic data.
- Self-learning adjusts SOC model parameters based on similar operating conditions.
- The system automatically extracts charge/discharge curves at different temperatures and adjusts the SOC model parameters accordingly.

e-STORAGE notes the estimated SOC estimation error is expected to be 3-5%. DNV finds the approach to be typical.

The SolBank 3.0 BMS recalibrates the SOC after a full charge/discharge, and the maintenance manual [42] states that the battery requires a full charge and discharge at least once every three months to calibrate the SOC.

DNV notes the SOC errors can accumulate during BESS operation due to factors such as measurement inaccuracies, battery self-discharge, and more. The accumulated error may vary depending on battery usage; for example, the SOC error for a battery that is charged/discharged daily can differ from one that remains mostly idle.

DNV reviewed the SOC accuracy test results [43] for various test scenarios: SOC tested under balanced aging conditions and initial SOC error. The report concluded that the calculated estimation error was within 3% for both test scenarios. DNV did not independently verify the reported results.

The maximum capacity (SOH/Q_{max}) is estimated using the following formula [44]:

$$Q_{max} = \frac{\Delta Q}{SOC_1 - SOC_2} = \frac{\int_{I_1}^{I_2} \lambda I dt}{SOC_1 - SOC_2}$$

Equation 1: Maximum capacity estimation method

Where ΔQ denotes the accumulation of battery power in the t_1, t_2 time interval; SOC_1 is state of charge at time t_1 ; SOC_2 is the state of charge at the time of t_2 . λ denotes correction coefficient close to 1 that is affected by current and temperature.

While the formula provides a simple SOH estimation, DNV recommends comparing the estimated SOH derived from Q_{max} with the actual capacity measured during a capacity test or SOC recalibration.

It appears that the SOH estimation method only captures linear characteristics of the system [45]. DNV notes that nonlinear characteristics may affect the accuracy of the SOH estimation results overtime.

5.6.4 Balancing

Balancing ensures that all cells or modules in a battery pack are charged and discharged evenly. This reduces the risk of operating cells at different voltage or SOC ranges and prevents uneven battery degradation within the system, thus maximizing the usable capacity of the BESS. Utility-scale BESS BMS are typically equipped with passive or active balancers to facilitate the extraction of the BESS usable capacity.

DNV considers SolBank 3.0's active balancing efficiency (93.74% and 89.97%) and strategy to be in line with industry, which takes approximately 1.5 hours to balance 1% capacity deviation.

The BMS monitors the battery cell status in real-time, analyzing voltage and capacity differences [40]. When voltage or capacity disparities between cells reach the conditions for balancing activation, the BMS opens the channel-selection switches for both high-energy and low-energy cells. Through a DC-DC circuit, high-energy cells transfer energy to low-energy cells. As energy transfer progresses, the discrepancies between cells diminish. When the voltage difference between corresponding cells decreases to the target value, or when the balancing duration is achieved, the BMS closes the relevant channel-selection switches, concluding a single balancing cycle, see Figure 5-7.

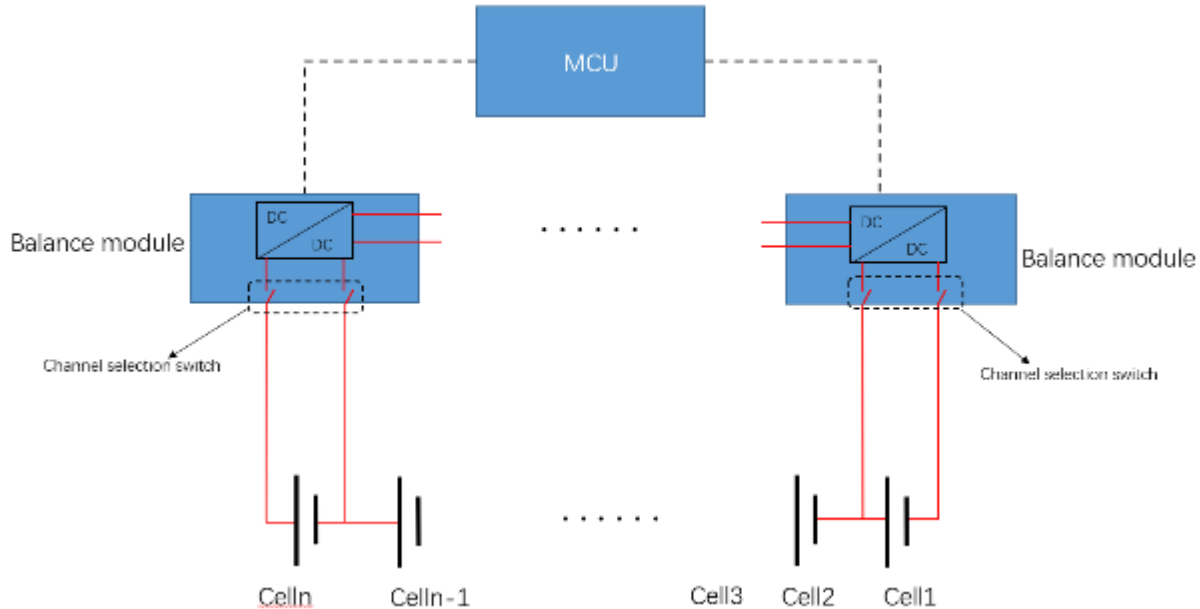


Figure 5-7 BMS Active balancing high level circuit Diagram

SolBank 3.0 uses an active balancing system that can be activated during charge, discharge or idle condition [41] for any individual cell. The BCM monitors individual cells within a cluster, identifying those with high and low states of charge (SOC). When the voltage difference between cells exceeds 20 mV, and the temperature is between 0 °C and 65 °C, with cell voltages ranging from 2.7 V to 3.6 V, and the system is not powered by a UPS, the BCM initiates energy transfer from high SOC cells to low SOC cells. The balancing is stopped when the cells' voltage difference is lower than 5 mV. Redundant hardware and fault detection algorithms are implemented to prevent misbalancing and protect cells.

The balancing can be activated at the whole open circuit voltage (OCV) curve, which DNV finds favorable, however temperature range is higher than the cell upper limit. DNV recommends aligning the upper temperature limit with the cell operational range as well as expected heat dissipation to inhibit the risk of accelerated degradation.

DNV notes active balancing is typically more efficient in maintaining even cell capacity and offers more flexibility in balancing time; however, it can increase heat dissipation, the risk of component failure, and system complexity. These issues can be mitigated through thoughtful design and testing. e-STORAGE provided DNV the pack level BMS test results [46]. The test results included verification of balancing current, balancing charge/discharge voltage balancing efficiency, power supply voltage, and temperature rise. DNV finds the test to be comprehensive.

The balancing circuit current is 2 A [47]. e-STORAGE noted that the balancing time is calculated based on the cell capacity, and to balance a 1% capacity difference, the total balancing time will be approximately 1.5 hours ($314 \text{ Ah} \times 1\% \div 2 \text{ A}$), which DNV considers favorable.

DNV has reviewed a test report on balancing efficiency [48], which evaluated the balancing efficiency under normal operating conditions. The report concluded the balancing efficiency in buck and boost modes to be 93.74% and 89.97%, respectively. DNV did not independently verify the test results.

Figure 5-8 shows the active balancing operational flowchart. When the SolBank 3.0 BMS is powered up, it initiates a self-check procedure that verifies cell voltage, cell temperature, sampling harness continuity, balance board temperature, and

current balancing status [40]. If the self-check fails, the BMS immediately disables the faulted balancing circuit, sends an alarm to the SolBank 3.0 controller, and reports the fault status to the EMS via Modbus/TCP. If the self-check passes, the BMS evaluates whether balancing should be initiated according to the active balancing algorithm. If conditions are met, the balancing circuit is turned on and an attempt is made to open the balancing channel. If the channel fails to open, the BMS records the fault, issues a shutdown signal, and uploads the alarm to the EMS. If the channel opens successfully, active balancing begins, with energy transferred between cells until the voltage or SOC difference falls within the stop threshold or the session-level timeout is reached. At timeout, the BMS halts balancing, logs the event, and can retry after a delay. At all times, balancing will pause if abnormal voltage or temperature conditions are detected, resuming only when conditions return to normal.

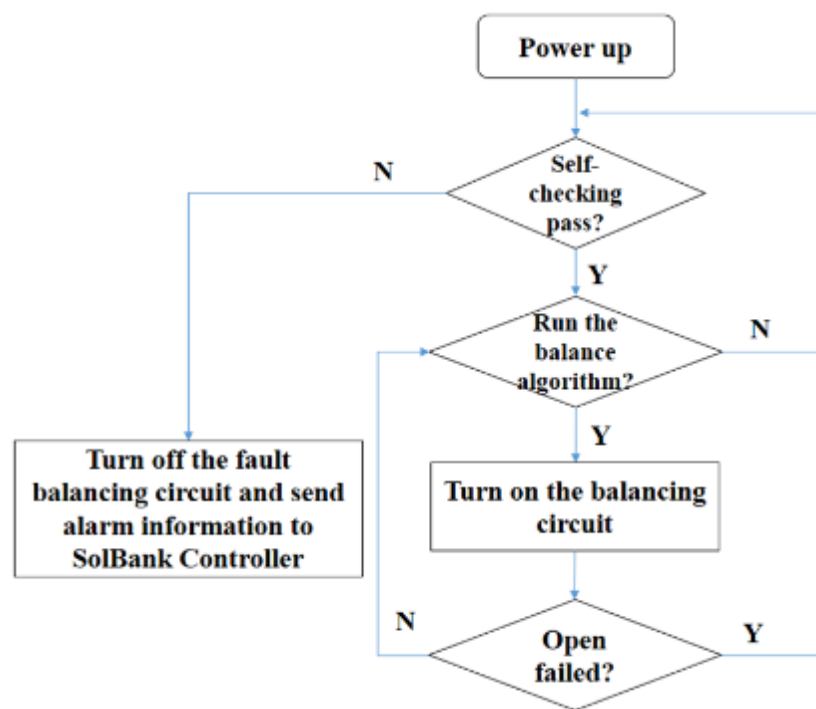


Figure 5-8 Active Balancing Flow Chart

The BMS's balancing algorithm employs a dual-strategy approach, using a primary voltage-based method and a secondary SOC-based method, see Figure 5-9. Voltage-based balancing starts when the cell-to-cell voltage difference exceeds the start limit of 20 mV and stops when the voltage difference is < 5 mV. SOC-based balancing engages when the SOC difference exceeds 3% and stops when the calculated target balancing duration is achieved, determined by $(\Delta \text{SOC} * \text{capacity}) / 2$. Exact balancing parameters utilized by the BMS's balancing algorithm are provided in Table 5-9. Both strategies can operate together, with voltage-based control taking precedence. Balancing direction is determined per cell as follows:

- **Charge balance:** When $\Delta V < 0$ or $\Delta \text{SOC} < 0$, it indicates the cell has a relatively low charge level. Here, a charge operation should be initiated by activating its balance channel to receive energy from cells with higher charge levels.

- Discharge balance: When $\Delta V > 0$ or $\Delta SOC > 0$, it indicates the cell has a relatively high charge level. In this case, a discharge operation should be performed by enabling its balance channel to transfer energy to cells with lower charge levels.

Throughout balancing, the BMS periodically re-evaluates ΔV and ΔSOC to decide whether to continue or stop. If an abnormal balance condition is detected, such as excessive ΔV or ΔSOC persisting despite balancing, balancing is stopped, a fault is logged, and an alarm is sent to the EMS.

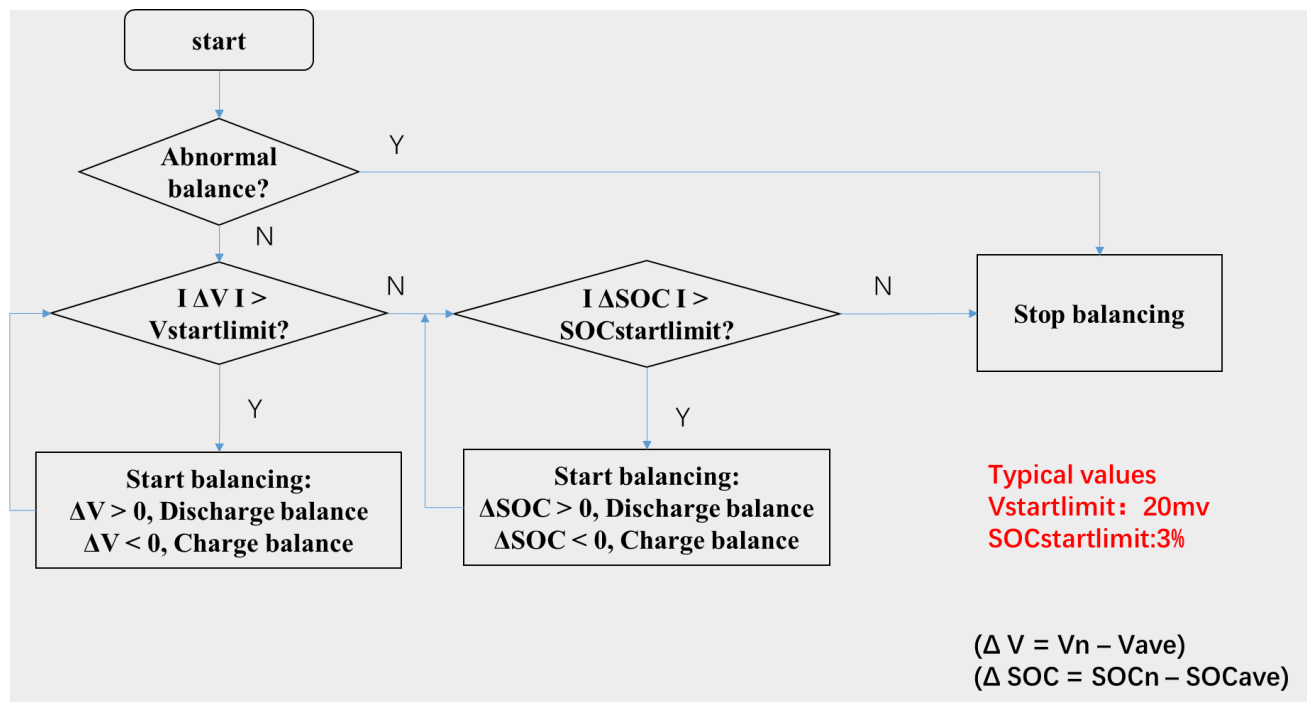


Figure 5-9 Active Balancing Algorithm

Table 5-9 Balancing Parameter

Parameter	Description	Default Value	Balancing Method
Vstartlimit	ΔV threshold to start balancing	20 mV	Voltage-Based
Vstoplimit	ΔV threshold to stop balancing	5 mV	Voltage-Based
SOCstartlimit	ΔSOC threshold to start balancing	3%	SOC-Based
Target Duration	Balance time target for SOC-based control	Calculated by $\Delta SOC * capacity / 2$	SOC-Based

5.6.5 Precharge protection

One of the safety and protection features of the BMS is protection against inrush current from the string level to the PCS. Typically, the precharge circuit acts as soft start circuit to limit inrush current through a resistor or other means.

The SolBank 3.0 precharge process appears to be logical and includes some fail-safe mechanisms. Thus, DNV considers the SolBank 3.0 precharge logic and circuit to be in line with industry standards.

Figure 5-10 shows a high level precharge circuit diagram that consists of contactors controlled by the BCM and resistor to limit inrush to the dc link. The BCM continuously monitors the voltage on both sides of the main positive and negative contactors. The dc-link capacitor is safely charged through the precharger resistor when the deviation in voltage measurement between the contactors' sides is below a certain threshold (5%). This allows the BCM to close the main positive contactor without the risk of high inrush current. Figure 5-11 shows the precharge algorithm, which includes some fail safe mechanism before (impedance and fault and alarms check) and during (60 second delay in operating precharge circuit) execution.

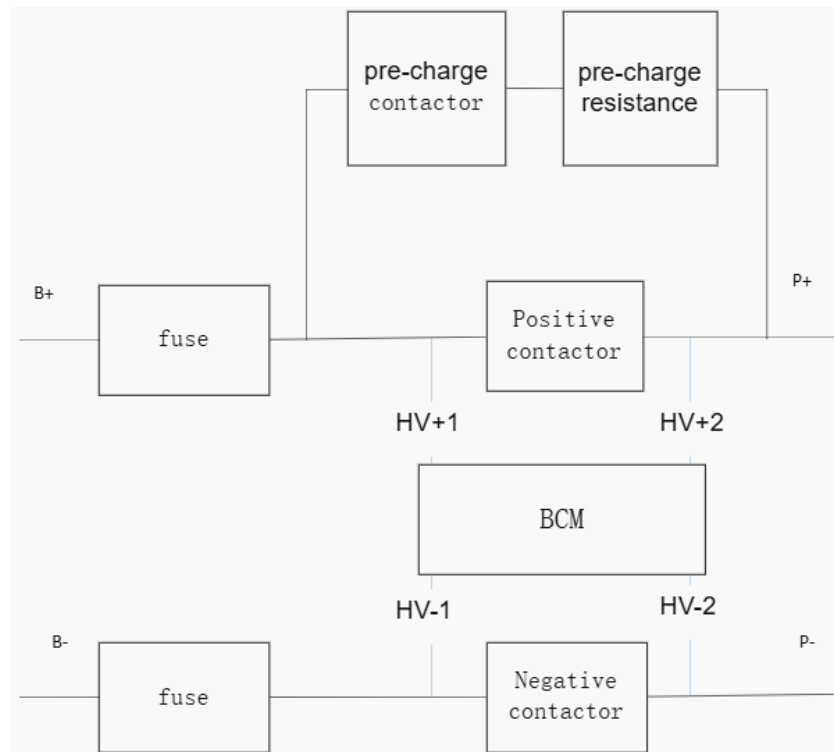


Figure 5-10 High level precharge circuit diagram

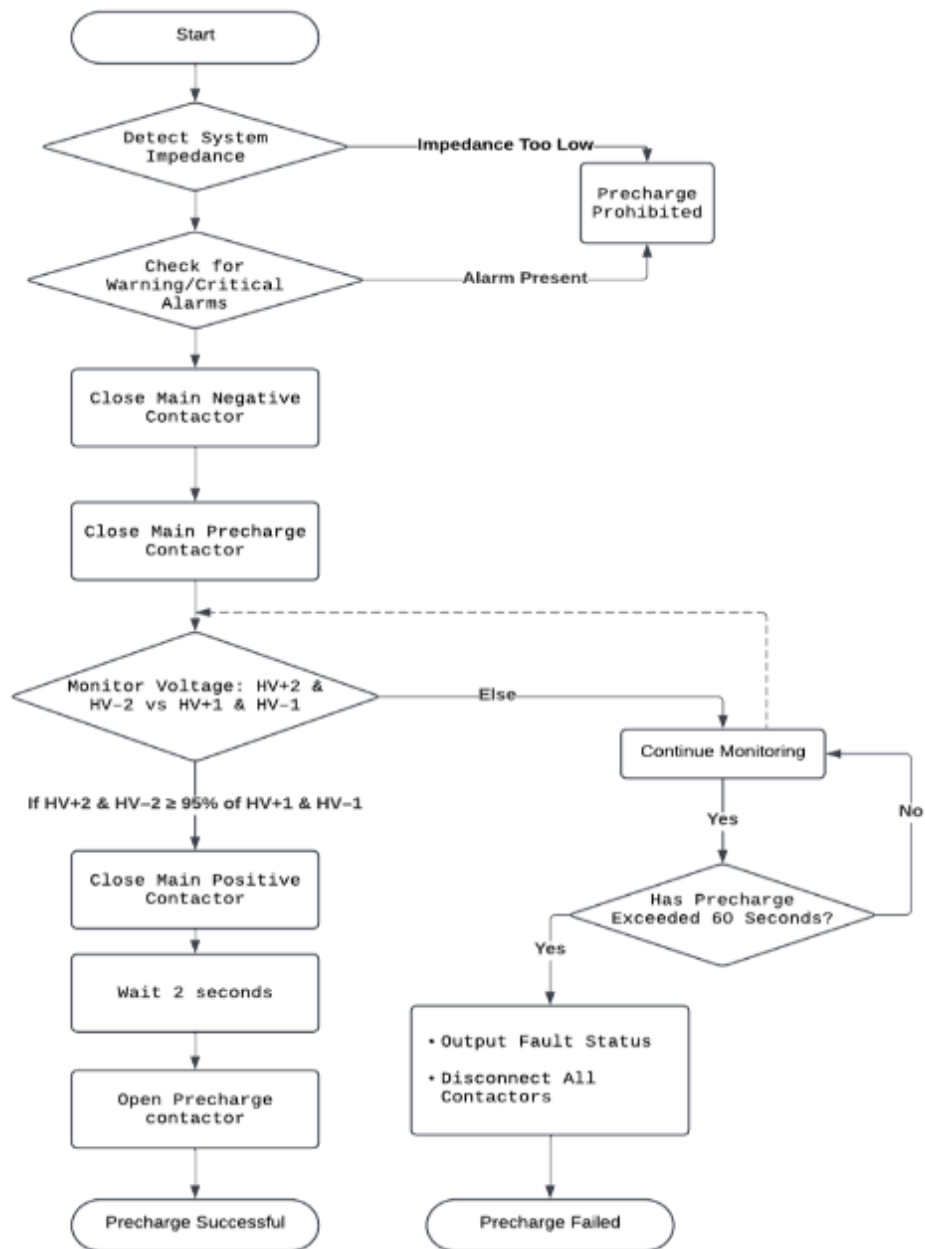


Figure 5-11 Precharge process flowchart

5.6.6 Insulation detection

Insulation detection circuit is employed to identify potential ground fault conditions, see Figure 5-12 [49]. The insulation fault detection function is handled by BCM, which monitors and protects the system at the pack/cluster level. The circuit's main elements consist of capacitors, resistors, switches, and voltage measurement devices. Its primary function is to sequentially operate the switches K1 and K2, enabling the control algorithm to calculate the insulation resistance paths—RH and RL—between the pack's positive and negative terminals and ground.

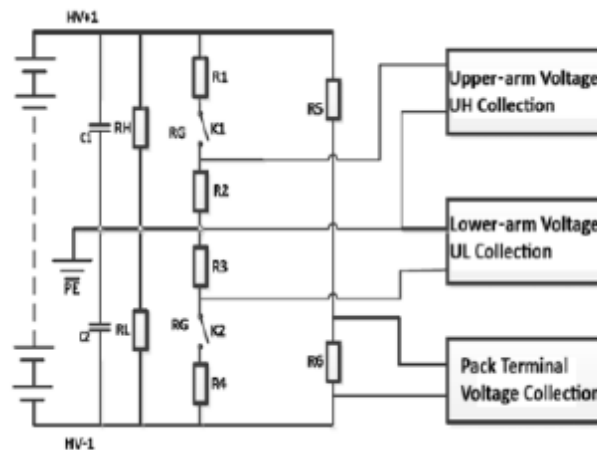


Figure 5-12 Insulation measurement circuit diagram

The adopted detection method applies basic Kirchhoff's current law (KCL) to solve the two unknown resistance values RH and RL. This method is initiated prior to the precharge operation. Figure 5-13 illustrates the flowcharts of the insulation detection sequence. The threshold values utilized in activating the alarms and faults for the insulation fault detection circuit are consistent with the low insulation resistance values specified in Table 5-8.

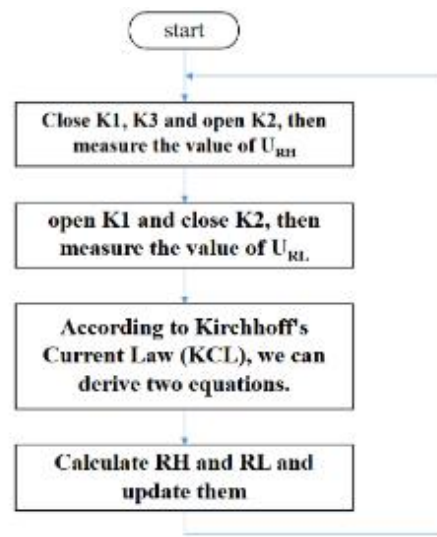


Figure 5-13 Insulation detection process flowchart

The insulation fault detection hardware interfaces with the BMS voltage sensing circuitry to continuously monitor the upper-arm voltage (U_H), lower-arm voltage (U_L), and total pack voltage (U_0). The control algorithm manages the switching of contactors K1 and K2, applies stabilization delays, and calculates insulation resistance once the measured voltages have settled.

The detection logic employs the following two-step switching sequence:

- Step 1
 - K1 is closed and K2 is opened
 - The BMS measures the upper-arm voltage (U_{H1})
 - The lower-arm voltage is calculated as: $U_{L1} = U_0 - U_{H1}$
- Step 2
 - K1 is opened and K2 is closed
 - The BMS measures the lower-arm voltage (U_{L2})
 - The upper-arm voltage is calculated as: $U_{H2} = U_0 - U_{L2}$

Based on the measured voltages and known resistor values, the BMS applies KCL to compute positive insulation resistance (R_H) and negative insulation resistance (R_L).

5.7 Regulatory compliance and safety

Safety is a critical design and operational aspect of energy storage systems. Safety of an energy storage system builds up from the battery cell and is relevant to every stage of product's lifecycle, based upon both code requirements and best practices. When assessing an energy storage device's safety program, DNV applies the approach of risk management; that is, the likelihood of an emergency event to occur and the severity of the event. DNV reviews certifications, test data, and quality management processes to address the likelihood factor of the equation; and reviews emergency response, installation protections, and suppression/detection systems to address the severity factor of the equation. In general, DNV considers certifications to codes and standards to be minimum requirements. Since codes and standards do not necessarily match up to best practices, DNV expects a robust safety program to go beyond the basic requirements.

In this section, DNV has reviewed the safety program for SolBank 3.0. DNV notes that the BESS can be configured with the following cell manufacturers: Hithium, e-STORAGE, EVE, Cornex and Sunwoda. The model numbers associated with SolBank 3.0 are found in Table 5-10.

Table 5-10 Model numbers of BESS components intended to be used in SolBank 3.0

Component	Cell supplier				
	Hithium	e-STORAGE	EVE	Cornex	Sunwoda
Cell	LFP71173207/314Ah	CSI314	MB31	PF173-314A	SBP-01-3140
Module	CSI-SolBank-P-104.5-2h-H, CSI-SolBank-P-104.5-4h-H	CSI-SolBank-P-104.5-2h-A, CSI-SolBank-P-104.5-4h-A	CSI-SolBank-P-104.5-2h-E, CSI-SolBank-P-104.5-4h-E	CSI-SolBank-P-104.5-2h-N/ CSI-SolBank-P-104.5-4h-N	CSI-SolBank-P-104.5-2h-X
Unit	CSI-SolBank-R-418-2h-H, CSI-SolBank-R-418-4h-H	CSI-SolBank-R-418-2h-A, CSI-SolBank-R-418-4h-A	CSI-SolBank-R-418-2h-E, CSI-SolBank-R-418-4h-E	CSI-SolBank-R-418-2h-N, CSI-SolBank-R-418-4h-N	CSI-SolBank-R-418-2h-X, CSI-SolBank-R-418-4h-X
Integrated BESS	CSI-SolBank-S-5016-2h-NA, CSI-SolBank-S-5016-4h-NA	CSI-SolBank-S-5016-2h-NA, CSI-SolBank-S-5016-4h-NA	CSI-SolBank-S-5016-2h-NA, CSI-SolBank-S-5016-4h-NA	CSI-SolBank-S-5016-2h-NA/ CSI-SolBank-S-5016-4h-NA	CSI-SolBank-R-418-2h-X, CSI-SolBank-R-418-4h-X

5.7.1 Standards, codes and testing

SolBank 3.0 and its subcomponents are designed to be compliant with standards that are generally accepted to demonstrate minimum safety considerations in the system design for US installations. These standards include certifications of the batteries by Underwriters Laboratories (UL) and International Electrotechnical Commission (IEC) standards, as well as UL and UN testing. A full listing of key standards claimed across several documents is provided in. DNV agrees that designing these standards is in line with best practices. In addition to the standards listed, DNV considers NFPA 855, the Standard for the Installation of Stationary Energy Storage Systems, as a best practice guide for all Projects. While not certifiable, DNV has considered some key regulations outlined in this standard as they pertain to the BESS.

Table 5-11 Standards, codes, and testing list (Hithium cell)

Component	Claimed Standard	Title	Certification/Test verified
Module/ Pack/ String	UL 1973:3 rd edition	Standard for Batteries for Use in Stationary, Vehicle Auxiliary Power and Light Electric Rail (LER) Applications	This standard specifies and evaluates the safety design aspects of multiple battery cells that are integrated into a module, pack, or string and operated in parallel/series, often with a BMS and other instrumentation, to withstand abuse conditions such as external short circuit, overcharge, over discharge, crush, shock, vibration, temperature cycling, low pressure, projectile, external fire, drop, molded case heating, and internal short circuit. DNV reviewed the UL 1973 certification and test report of model #CSI-SolBank-R-418-2h-H and CSI-SolBank-R-418-4h-H utilizing Hithium cells and confirms compliance [50] [51]. Additionally, DNV confirms that the UL 1973 certification is applicable to both the 2-hour and 4-hour DC BESS configurations.
DC ESS	UL 9540: 3 rd edition	Standard for Energy Storage Systems and Equipment (DC system)	This certification is an IFC requirement in which the BESS must be listed to UL 9540. DNV notes that compliance can be acquired through certification before or after a Project's construction begins. If on-site integration is required, DNV finds typical timelines for UL 9540 evaluations to occur before COD due to on-site testing requirements. DNV reviewed the UL 9540 test report and certificate of BESS model #CSI-SolBank-S-5016-2h-NA and CSI-SolBank-S-5016-4h-NA utilizing Hithium cells and confirms the compliance [52] [53] [54]. Additionally, DNV confirms that the UL 9540 certification is applicable to both the 2-hour and 4-hour DC BESS configurations.
Full system fault and fire testing	UL 9540A:4 th edition	Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems – cell, module, unit	Hithium cells (model #LFP71173207/314Ah) utilized in SolBank 3.0 have been tested to the 4th edition of UL 9540A. The test reports were issued by TUV Rheinland [55]. The battery module (model #CSI-SolBank-P-104.5-2h-H and CSI-SolBank-P-104.5-4h-H) utilized in SolBank 3.0 has been tested to the 4th edition of UL 9540A. The test report was issued by TUV Rheinland [56]. The Unit (model #CSI-SolBank-R-418-2h-H and CSI-SolBank-R-418-4h-H) utilized in SolBank 3.0 has been tested to the 4th edition of UL 9540A. The test report was issued by TUV Rheinland [57].

Table 5-12 Standards, codes, and testing list (e-STORAGE cell)

Component	Claimed Standard	Title	Certification/Test verified
Module/ Pack/ String	UL 1973:3 rd edition	Standard for Batteries for Use in Stationary, Vehicle Auxiliary Power and Light Electric Rail (LER) Applications	This standard specifies and evaluates the safety design aspects of multiple battery cells that are integrated into a module, pack, or string and operated in parallel/series, often with a BMS and other instrumentation, to withstand abuse conditions such as external short circuit, overcharge, over discharge, crush, shock, vibration, temperature cycling, low pressure, projectile, external fire, drop, molded case heating, and internal short circuit. DNV reviewed the UL 1973 certification and test report of model #CSI-SolBank-R-418-2h-A and CSI-SolBank-R-418-4h-A utilizing the e-STORAGE cell and confirms compliance [58] [59]. Additionally, DNV confirms that the UL 1973 certification is applicable to both the 2-hour and 4-hour DC BESS configurations.
DC ESS	UL 9540: 3 rd edition	Standard for Energy Storage Systems and Equipment (DC system)	This certification is an IFC requirement in which the BESS must be listed to UL 9540. DNV notes that compliance can be acquired through certification before or after a Project's construction begins. If on-site integration is required, DNV finds typical timelines for UL 9540 evaluations to occur before COD due to on-site testing requirements. DNV reviewed the UL 9540 test report and certificate of BESS model #CSI-SolBank-S-5016-2h-NA and CSI-SolBank-S-5016-4h-NA utilizing the e-STORAGE cell and confirms the compliance [60] [61]. Additionally, DNV confirms that the UL 9540 certification is applicable to both the 2-hour and 4-hour DC BESS configurations.
Full system fault and fire testing	UL 9540A:4 th edition	Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems – <i>cell, module, unit</i>	The e-STORAGE cell (model #CSI314) utilized in SolBank 3.0 has been tested to the 4th edition of UL 9540A. The test reports were issued by TUV Rheinland [62]. The battery module (model #CSI-SolBank-P-104.5-2h-A and CSI-SolBank-P-104.5-4h-A) utilized in SolBank 3.0 has been tested to the 4th edition of UL 9540A. The test report was issued by TUV Rheinland [63]. The Unit (model #CSI-SolBank-R-418-2h-A and CSI-SolBank-R-418-4h-A) utilized in SolBank 3.0 has been tested to the 4th edition of UL 9540A. The test report was issued by TUV Rheinland [64].

Table 5-13 Standards, codes, and testing list (EVE cell)

Component	Claimed Standard	Title	Certification/Test verified
Module/ Pack/ String	UL 1973	Standard for Batteries for Use in Stationary, Vehicle Auxiliary Power and Light Electric Rail (LER) Applications	This standard specifies and evaluates the safety design aspects of multiple battery cells that are integrated into a module, pack, or string and operated in parallel/series, often with a BMS and other instrumentation, to withstand abuse conditions such as external short circuit, overcharge, over discharge, crush, shock, vibration, temperature cycling, low pressure, projectile, external fire, drop, molded case heating, and internal short circuit. DNV reviewed the UL 1973 certification and test report of model # CSI-SolBank-R-418-2h-E and CSI-SolBank-R-418-4h-E utilizing EVE cells and confirms compliance [65] [66]. Additionally, DNV confirms that the UL 1973 certification is applicable to both the 2-hour and 4-hour DC BESS configurations.
DC ESS	UL 9540	Standard for Energy Storage Systems and Equipment (DC system)	This certification is an IFC requirement in which the BESS must be listed to UL 9540. DNV notes that compliance can be acquired through certification before or after a Project's construction begins. If on-site integration is required, DNV finds typical timelines for UL 9540 evaluations to occur before COD due to on-site testing requirements. DNV reviewed the UL 9540 test report and certificate of BESS model #CSI-SolBank-S-5016-2h-NA, CSI-SolBank-S-5016-4h-NA utilizing EVE cells and confirms the compliance [67] [68]. Additionally, DNV confirms that the UL 9540 certification is applicable to both the 2-hour and 4-hour DC BESS configurations.
Full system fault and fire testing	UL 9540A	Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems – <i>cell, module, unit</i>	EVE cells (model # MB31) utilized in SolBank 3.0 have been tested to the 4th edition of UL 9540A. The test reports were issued by UL LLC [69]. The battery module (model # CSI-SolBank-P-104.5-2h-E and CSI-SolBank-P-104.5-4h-E) utilized in SolBank 3.0 has been tested to the 4th edition of UL 9540A. The test report was issued by TUV Rheinland [70]. The Unit (model # CSI-SolBank-R-418-2h-E and CSI-SolBank-R-418-4h-E) utilized in SolBank 3.0 has been tested to the 4th edition of UL 9540A. The test report was issued by TUV Rheinland [71].

Table 5-14 Standards, codes, and testing list (Cornex cell)

Component	Claimed Standard	Title	Certification/Test verified
Module/ Pack/ String	UL 1973: 3 rd edition	Standard for Batteries for Use in Stationary, Vehicle Auxiliary Power and Light Electric Rail (LER) Applications	This standard specifies and evaluates the safety design aspects of multiple battery cells that are integrated into a module, pack, or string and operated in parallel/series, often with a BMS and other instrumentation, to withstand abuse conditions such as external short circuit, overcharge, over discharge, crush, shock, vibration, temperature cycling, low pressure, projectile, external fire, drop, molded case heating, and internal short circuit. DNV reviewed the UL 1973 3rd edition certification and test report of model # CSI-SolBank-R-418-2h-N and CSI-SolBank-R-418-4h-N utilizing Cornex cells and confirms compliance [72] [73]. Additionally, DNV confirms that the UL 1973 certification is applicable to both the 2-hour and 4-hour DC BESS configurations.
DC ESS	UL 9540: 3 rd edition	Standard for Energy Storage Systems and Equipment (DC system)	This certification is an IFC requirement in which the BESS must be listed to UL 9540. DNV notes that compliance can be acquired through certification before or after a Project's construction begins. If on-site integration is required, DNV finds typical timelines for UL 9540 evaluations to occur before COD due to on-site testing requirements. DNV reviewed the UL 9540 3rd edition test report and certificate of BESS model #CSI-SolBank-S-5016-2h-NA and CSI-SolBank-S-5016-4h-NA utilizing Cornex cells and confirms the compliance [74] [75]. Additionally, DNV confirms that the UL 9540 certification is applicable to both the 2-hour and 4-hour DC BESS configurations.
Full system fault and fire testing	UL 9540A: 4 th edition	Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems – <i>cell, module, unit</i>	Cornex cells (model #PF173-314A) utilized in SolBank 3.0 have been tested to the 4th edition of UL 9540A. The test reports were issued by UL LLC [76]. The battery module (model # CSI-SolBank-P-104.5-2h-N and CSI-SolBank-P-104.5-4h-N) utilized in SolBank 3.0 has been tested to the 4th edition of UL 9540A. The test report was issued by TUV Rheinland [77]. The Unit (model # CSI-SolBank-R-418-2h-N and CSI-SolBank-R-418-4h-N) utilized in SolBank 3.0 has been tested to the 4th edition of UL 9540A. The test report was issued by TUV Rheinland [78].

Table 5-15 Standards, codes, and testing list (Sunwoda cell)

Component	Claimed Standard	Title	Certification/Test verified
Module/ Pack/ String	UL 1973:3 rd edition	Standard for Batteries for Use in Stationary, Vehicle Auxiliary Power and Light Electric Rail (LER) Applications	This standard specifies and evaluates the safety design aspects of multiple battery cells that are integrated into a module, pack, or string and operated in parallel/series, often with a BMS and other instrumentation, to withstand abuse conditions such as external short circuit, overcharge, over discharge, crush, shock, vibration, temperature cycling, low pressure, projectile, external fire, drop, molded case heating, and internal short circuit. DNV reviewed the UL 1973 3rd edition certification and test report of model #CSI-SolBank-R-418-2h-X and CSI-SolBank-R-418-4h-X utilizing Sunwoda cells and confirms compliance [79] [80]. Additionally, DNV confirms that the UL 1973 certification is applicable to both the 2-hour and 4-hour DC BESS configurations.
DC ESS	UL 9540: 3 rd edition	Standard for Energy Storage Systems and Equipment (DC system)	This certification is an IFC requirement in which the BESS must be listed to UL 9540. DNV notes that compliance can be acquired through certification before or after a Project's construction begins. If on-site integration is required, DNV finds typical timelines for UL 9540 evaluations to occur before COD due to on-site testing requirements. DNV reviewed the UL 9540 3rd edition test report and certificate of BESS model #CSI-SolBank-S-5016-2h-NA and CSI-SolBank-S-5016-4h-NA utilizing Cornex cells and confirms the compliance [81] [82]. Additionally, DNV confirms that the UL 9540 certification is applicable to both the 2-hour and 4-hour DC BESS configurations.
Full system fault and fire testing	UL 9540A: 4 th edition	Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems – <i>cell, module, unit</i>	Sunwoda cells (model # SBP-01-3140) utilized in SolBank 3.0 have been tested to the 4th edition of UL 9540A. The test reports were issued by TUV Rheinland [83] . The battery module (model # CSI-SolBank-P-104.5-2h-X) utilized in SolBank 3.0 has been tested to the 4th edition of UL 9540A. The test report was issued by TUV Rheinland [84]. The Unit (model # CSI-SolBank-R-418-2h-X and CSI-SolBank-R-418-4h-X) utilized in SolBank 3.0 has been tested to the 4th edition of UL 9540A. The test report was issued by TUV Rheinland [85].

5.7.2 UL 9540A testing

UL 9540A testing is a destructive test method used for evaluating the thermal runaway impacts in a BESS and gathering data to assist in assessing or developing mitigation measures for the failure event, propagation of the failure, or consequences of an event, such as an explosion or fire. The test, which does not have pass/fail criteria, can be performed on a cell, module, or unit level. UL 9540A is ANSI (American National Standards Institute) accredited and is currently considered to be the most appropriate published methodology to provide comprehensive, consistent, and reliable third-party data for battery failure testing. DNV notes that UL 9540A is a requirement for the UL 9540 certification mandated by code in Section 1207.11.1 of the 2024 IFC.

DNV has received 4th edition testing of the cell, module, and unit level for SolBank 3.0 utilizing Hithium, e-STORAGE, EVE, Cornex and Sunwoda cells. The following is a summary of the UL 9540A test results:

- Hithium cell: In the cell-level test, the cell venting and thermal runaway onset temperatures were recorded at 203.7 °C and 295.7 °C, respectively. DNV notes that these temperatures are higher than typically observed for LFP battery chemistries. The module-level test report stated that three additional adjacent cells were affected due to propagation from two initiating cells, however based on the heater arrangement, this should be understood as one cell was initiated and cell-to-cell propagation occurred to four additional cells. DNV confirms that the unit-level test met all performance criteria outlined in the UL 9540A test methodology. Therefore, the separation distances used during testing may be adopted as the minimum separation distances for actual installations. Detailed test results, observations, and performance criteria are discussed in Appendix A.6 herein.
- e-STORAGE: In the cell-level test, the cell venting and thermal runaway onset temperatures were recorded at 167.4 °C and 238.5 °C, respectively. DNV notes that these temperatures are average that typically observed for LFP battery chemistries. The module-level test report stated that two additional adjacent cells were affected due to propagation from three initiating cells, however based on the heater arrangement, this should be understood as one cell was initiated and cell-to-cell propagation occurred to four additional cells. DNV confirms that the unit-level test met all performance criteria outlined in the UL 9540A test methodology. Therefore, the separation distances used during testing may be adopted as the minimum separation distances for actual installations. Detailed test results, observations, and performance criteria are discussed in Appendix B.5 herein.
- EVE cell: In the cell-level test, the cell venting and thermal runaway onset temperatures were recorded at 154.0 °C and 225.0 °C, respectively. DNV notes that these temperatures are below than typically observed for LFP battery chemistries. The module-level test report stated that one additional adjacent cell was affected due to propagation from two initiating cells, however based on the heater arrangement, this should be understood as one cell was initiated and cell-to-cell propagation occurred to two additional cells. DNV confirms that the unit-level test met all performance criteria outlined in the UL 9540A test methodology. Therefore, the separation distances used during testing may be adopted as the minimum separation distances for actual installations. Detailed test results, observations, and performance criteria are discussed in Appendix C.4 herein.
- Cornex cell: In the cell-level test, the cell venting and thermal runaway onset temperatures were recorded at 157.0 °C and 236 °C, respectively. DNV notes that the cell venting temperature is below average, while the thermal runaway temperature is higher than what DNV typically observes for LFP battery chemistry. As noted in the module-level test report, two additional adjacent cells were affected due to propagation from three initiating cells, however based on the heater arrangement, this should be understood as one cell was initiated and cell-to-cell propagation occurred to four additional cells. DNV confirms that the unit-level test met all performance criteria outlined in the UL 9540A test methodology. Therefore, the separation distances used during testing may be adopted as the minimum separation distances for actual installations. Detailed test results, observations, and performance criteria are discussed in Appendix D.4 herein.

- Sunwoda cell: In the cell-level test, the cell venting and thermal runaway onset temperatures were recorded at 121.0 °C and 168.5 °C, respectively. DNV notes that these temperatures are below than typically observed for LFP battery chemistries. Per UL 9540A test methodology, the UL 9540A cell level test did not meet the performance criteria. In the module-level test, four additional cells were affected due to propagation from a single initiating cell. DNV confirms that the unit-level test met all performance criteria outlined in the UL 9540A test methodology. Therefore, the separation distances used during testing may be adopted as the minimum separation distances for actual installations. Detailed test results, observations, and performance criteria are discussed in Appendix E.5 herein.

5.7.3 Safety design and features

- Introduction to Fire Protection System Diagram [87]
- Safety Manual SolBank 3.0 [88]
- BESS Fire Safety & FAQ [89]
- SolBank 3.0 Installation Manual, Version 1.2 [90]
- SolBank 3.0 0.25P Fire Safety System Location Details [91]
- SolBank 3.0 0.5P Fire safety System Location Details [92]

Fire and thermal runaway detection

Methodology: SolBank 3.0 employs a combination of smoke detectors and temperature sensors to detect smoke from an electrical fire, cell venting or hotspots in regions of the enclosure that are likely experiencing a thermal event.

Equipment: SolBank 3.0 is equipped with the following fire detection equipment: three smoke detectors, three heat detectors, two H₂ detectors, one fire alarm control panel (FACP), one sound and light alarm, alarm bell, one emergency start/stop button of the fan and two F-stop (emergency stop) buttons [72] [89] .

Triggers: The sensors discussed above are configured to detect if the environment in the enclosure deviates from a preset value. Table 5-16 describes the fire detection function provided in the BESS. DNV reviewed the fire alarm sequence operation, which states that depending on fire alarm from smoke, heat and Level 1 or Level 2 alarm signals from gas detectors, the FACP initiate mitigation measures such as activation of fire alarm, stop charging/discharging, activation of ventilation system, and activation of aerosol FSS (if installed). DNV finds the alarm sequence to be in line with industry expectations.

Table 5-16 Fire detection summary

Detection criteria	Quantity	DNV comment
Smoke detection	3	In the event of off-gassing, smoke detectors are likely to detect if cells experience venting or thermal runaway.
Gas detection	2	The UL 9540A cell level testing indicates H ₂ is the most prevalent gas during off-gassing. Therefore, H ₂ detectors are likely to detect events of thermal runaway.
Heat detection	3	Cell venting and thermal runaway occur roughly after 150 °C and 230 °C, respectively. Hence, heat detectors are set to trigger at 85 °C and appropriate mitigation actions intend to prevent venting and thermal runaway events.

DNV notes these sensors and detection systems require periodic maintenance and calibration as recommended by the manufacturer. Therefore, DNV recommends that the maintenance and calibration activity should be included in the BESS O&M agreement of any Project.

Fire Suppression

A well-engineered fire suppression system is characterized by its response-time, reliability, and the use of tested, purpose-designed agents and deployment mechanisms. The agent and mechanism must align with the overall thermal runaway management and safety strategy of a given Project.

Fire Suppression agent and application: SolBank 3.0 is equipped with the following fire suppression system: four aerosol fire suppression system (FSS) (optional) and a dry pipe FSS (optional). Figure 5-14 and Figure 5-15 displays the location of the aerosol and dry pipe FSS. DNV notes that the ability of aerosols is for small or non-battery fires. Aerosols lack the ability to adequately cool batteries during a thermal event and for larger battery fires, it is not expected to be effective. However, DNV finds the use of aerosol appropriate in the electrical section of the enclosure. Aerosols have proven to be effective in suppressing electrical fires within battery enclosures, which could have led to fire involving the batteries.

If the optional dry pipe FSS is installed, the BESS enclosure will have a water hose coupling point on side of the enclosure and 2 drains are provided on the floor which are installed for removing water within the BESS enclosure.

DNV recommends that, when installed, the aerosol FSS to be installed in accordance with NFPA 2010 requirements and dry pipe to be installed in accordance with NFPA 13 guidelines.

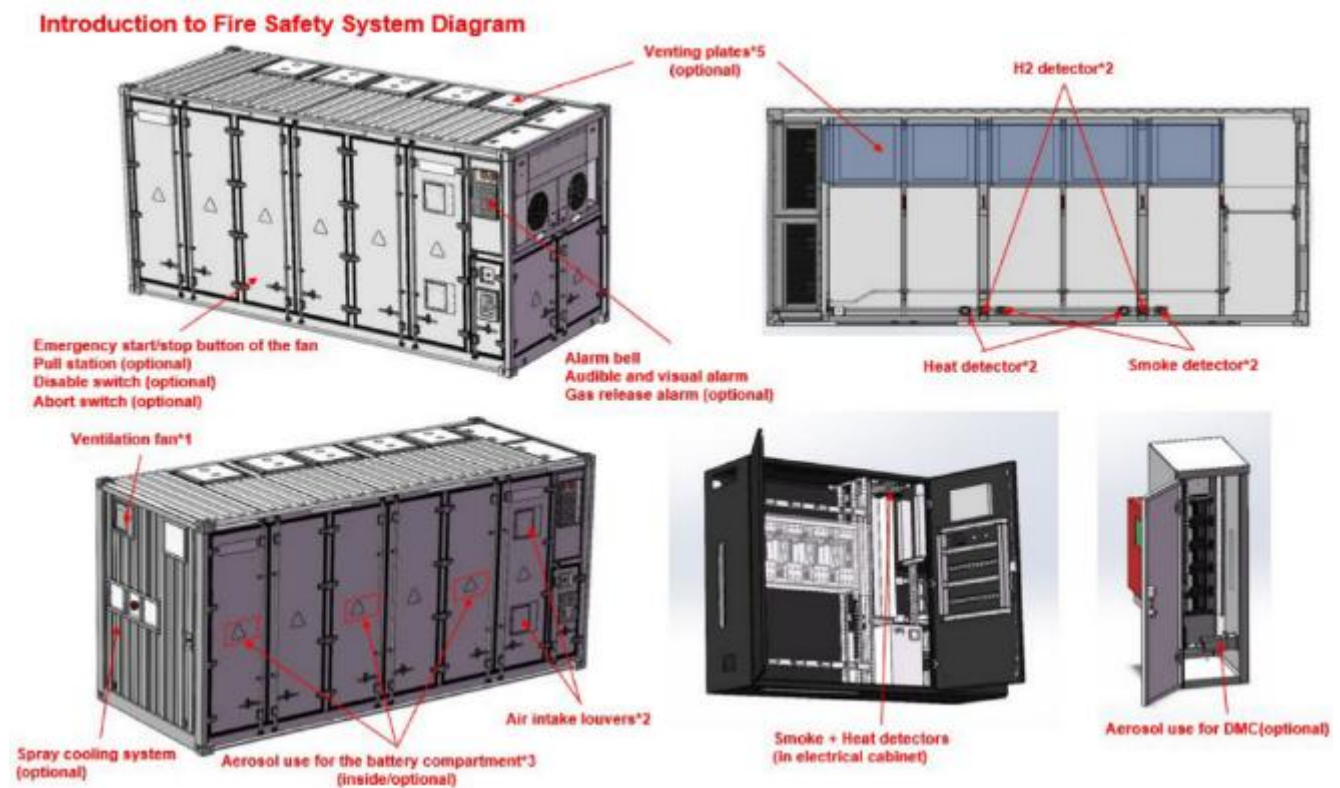


Figure 5-14 SolBank 3.0 fire and explosion protection system

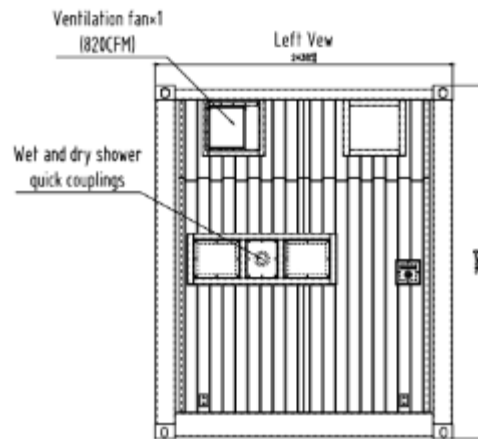


Figure 5-15 Optional dry pipe FSS

Standby power: As per NFPA 855:2023 article 4.8.3, smoke and fire detection systems protecting BESS installations with lithium-ion batteries are required to have a secondary power supply in accordance with NFPA 72 capable of 24 hours in standby and two hours in alarm. CSI stated that SolBank 3.0 is equipped with a dedicated FACP UPS (Uninterruptible Power Supply), which provides 24 hours backup power for fire alarm devices including FACP, smoke detectors, heat detectors, gas detectors, fire alarm bell and strobe [89]. Additionally, the ventilation system, which includes exhaust fan, air intake louvers, and BMS, are backed with a DMC UPS, which provides two hours backup power. DNV considers this best practice. The NFPA 855 guidelines further recommend using the HMA and UL 9540A testing as a basis for extending the backup duration, as appropriate.

5.7.3.2 Explosion prevention (NFPA 69)

SolBank 3.0 is equipped with both an explosion prevention and an explosion protection system. DNV finds the use of both explosion prevention and protection system within SolBank 3.0 to be in line with industry best practices.



Figure 5-16 Explosion prevention venting system

Compliance with NFPA 69 is specific to each cell. DNV's analysis for each cell can be found in the "Explosion prevention" section in the appropriate cell's Appendix. The general design and methodology, however, are consistent for each version of SolBank 3.0. The explosion/deflagration prevention system is designed to reduce the concentration of flammable gas inside the BESS enclosure to below 25% of the Lower Flammable Limit (LFL) by means of a ventilation system. The ventilation system is comprised of hydrogen gas sensors and an exhaust fan and air intake louvers shown in **Figure 5-16**. The exhaust fan is triggered when hydrogen gas levels inside the enclosure reach 10% LFL. DNV has reviewed the NFPA 69 analysis reports for SolBank 3.0 utilizing Hithium, e-STORAGE, EVE, Cornex, and Sunwoda cells. Simulations for all five cells demonstrate that the ventilation system can maintain flammable gas concentrations below 25% of LFL for all modeled cases, meeting NFPA 69 requirements.

5.7.3.3 Explosion protection (NFPA 68)

The SolBank 3.0 BESS enclosure uses a deflagration panel venting system for protection. In the event of a deflagration within the enclosure, the deflagration panels rupture at a predetermined pressure, relieving the excess overpressure by venting it outside the enclosure. This venting helps minimize damage to the enclosure and nearby assets. DNV has reviewed the NFPA 68 analysis reports for SolBank 3.0 utilizing Hithium, e-Storage, and Cornex cells [93] [94] [95]. Based on the findings presented in these reports, DNV concludes that the SolBank 3.0 design meets the applicable NFPA 68 requirements. Compliance with NFPA 68 is evaluated for each cell type used in the SolBank 3.0 BESS. DNV's detailed analysis for each cell is provided in the "Explosion Protection" section of the corresponding cell-specific Appendix.

Note on the NFPA 68 applicability extending to other cells used by e-STORGE (CSI):

Deviations in chemistry, release rates, and vent gas compositions can render a previously adequate vent area undersized, or delay panel opening, which may put the design out of compliance. DNV has not reviewed the NFPA 68 venting analysis, testing, or selection criteria for configurations utilizing EVE and Sunwoda cells. e-STORAGE informed DNV that at this stage, NFPA 68 testing for these cell types has not yet been completed, as there are currently no active projects requiring deflagration panels for such configurations. As a result, the applicability of NFPA 68 compliance to EVE and Sunwoda-based systems should be confirmed as needed and evaluated on a project-specific basis, consistent with the optional nature of deflagration panels for SolBank 3.0.

5.7.3.4 Safety controls

SolBank 3.0 is equipped with one dedicated FACP, which acts as the control and monitoring center for all protection devices within the BESS. It also provides an interface to the BMS and other optional devices onsite. DNV reviewed the fire alarm sequence operation as described in the Table 5-17. It describes the combustible gas level alarm as Level 1 and Level 2. The threshold limits for combustible gas alarm Level 1 and Level 2 are 10% LEL and 20% of LEL [96]. DNV notes that the threshold limit for the heat detector is 85 °C, smoke detector is 3.5%/ft. The last column of the Table 5-17 defines the actions and status of the BESS.

Table 5-17 Fire alarm Sequence of Operations

Combustible gas Level 1 alarm	Combustible gas Level 2 alarm	Smoke detector alarm	Heat detector alarm	Ventilation Fan	Alarm Bell	Horn Strobe (Fire)	Horn Strobe (Gas)	Aerosol Based Fire Suppression	Running status of the energy storage system
×	×	×	×	Close	Close	Close	Close	Close	No fire alarm, the system runs normally
✓	×	×	×	Open	Open	Close	Open	Close	Combustible Level 1 alarm, the system is forbidden to charge and discharge, auxiliary AC switch and DC contactor are closed
✓	✓	×	×	Open	Open	Close	Open	Close	Combustible Level 2 alarm, the system is forbidden to charge and discharge, auxiliary AC switch and DC contactor are disconnected
×	×	✓	×	Close	Open	Close	Close	Close	Fire alarm Level 1, the system is forbidden to charge and discharge, auxiliary AC switch and DC contactor are closed
✓	×	✓	×	Open	Open	Close	Open	Close	Combustible, fire alarm Level 1, the system is forbidden to charge and discharge, auxiliary AC switch and DC contactor are closed
✓	✓	✓	×	Open	Open	Close	Open	Close	Combustible alarm Level 2, fire alarm Level 1, the system is forbidden to charge and discharge, auxiliary AC switch and DC contactor are disconnected
×	×	×	✓	Close	Open	Close	Close	Close	Fire alarm Level 1, the system is forbidden to charge and discharge, auxiliary AC switch and DC contactor are closed
✓	×	×	✓	Open	Open	Close	Open	Close	Combustible, fire alarm Level 1, the system is forbidden to charge and discharge, auxiliary AC switch and DC contactor are closed
✓	✓	×	✓	Open	Open	Close	Open	Close	Combustible alarm Level 2, fire alarm Level 1, the system is forbidden to charge and discharge, auxiliary AC switch and DC contactor are disconnected

Combustible gas Level 1 alarm	Combustible gas Level 2 alarm	Smoke detector alarm	Heat detector alarm	Ventilation Fan	Alarm Bell	Horn Strobe (Fire)	Horn Strobe (Gas)	Aerosol Based Fire Suppression	Running status of the energy storage system
×	×	✓	✓	Close	Open	Open	Close	Open	Fire alarm Level 2, the system is forbidden to charge and discharge, auxiliary AC switch and DC contactor are disconnected
✓	×	✓	✓	Open	Open	Open	Open	Close	Combustible Level 1, fire Level 2 alarm, the system is forbidden to charge and discharge, auxiliary AC switch and DC contactor are disconnected
✓	✓	✓	✓	Open	Open	Open	Open	Close	Combustible Level 2, fire Level 2 alarm, the system is forbidden to charge and discharge, auxiliary AC switch and DC contactor are disconnected

DNV has identified critical safety control system features that align with industry best practices. As described in Table 5-18, these attributes are crucial for ensuring that safety control systems function reliably, protecting both individuals and assets effectively.

DNV has characterized key safety control system attributes that represent industry best practices. These system attributes are essential for ensuring that safety control systems consistently perform as intended, safeguarding both people and assets. Table 5-18 displays the safety control characteristics.

Table 5-18 Safety control system attributes

Attribute	Description	DNV comments
Interlocks	The safety control system interlocks with BMS, EMS, site level monitoring to clearly conveying trouble signals to initiate total system shutdown.	The FACP is configured with interlock functions, which includes BMU at module level, battery cluster/pack unit (BCU) at cluster/pack level and SolBank Controller at system level. Additionally, the site EMS will communicate with fleet controller and SCADA operation center or 3rd party monitoring entity. Therefore, the alarms received by FACP, are monitored by remote operation center and, if deemed to be necessary, BESS can be shutdown by remote operator [88].
Time variance and escalation	The safety control system escalates response behaviors with time.	The safety control of SolBank 3.0 is configured with Level 1 alarm and Level 2 alarms. If any single detector is triggered, Level 1 alarm is activated. Any additional detectors during Level 1 alarm, escalates to Level 2 alarm. In Level 2 alarm, all BMS DC contactors will open and auxiliary power will be disconnected from the BESS. However critical loads will continue to operate by UPS backup power.
Event differentiation	The safety control system has distinct behaviors towards electrical fires and battery fires	DNV notes that SolBank 3.0 is equipped with smoke, heat and gas detection system, which differentiate between off-gassing events, fire incidents, or explosion occurrences. DNV considers the implementation of distinct safety control functions for thermal runaway and electrical fire events to be aligned with industry best practices.
Redundancy	The safety control system has redundant logic loops to trigger safety responses if one or more critical detection systems malfunction.	The safety control of the BESS is designed with redundant logic, including multiple detectors and the escalation of notifications from the BMU to the site level EMS. In the event of one or more sensors failure scenario, additional sensors will able to detect the event and send signal to FACP. Additionally, if noticed by site-personnel, manual shutdown can be initiated by F-Stop (emergency stop) button. DNV considers the implementation of redundancy in safety control to align with industry best practices.
Multi-criteria detection response	The safety control system accepts signals from multiple detection criteria to select and appropriate response.	Per Section 5.7.3 herein, multicriteria detectors such as smoke, heat and flammable gas detectors, are installed within the enclosure, which sends appropriate signal to the FACP and FACP is configured to initiate the trigger actions as displayed in Table 5-18.
Self-monitoring	The safety control system can monitor its status and signal the operator if any of the loops are malfunctioning.	As stated in Section 5.6, the SolBank 3.0 is configured as 12 racks/strings and 4 battery packs per string. Each rack/string is controlled and monitored by a dedicated BMU, BCU and BMS. If any monitoring parameter exceeds the limit, BMS will disconnect effected string, and an alarm will be sent to site EMS or other remote monitoring facility [97].

5.7.4 Hazard mitigation analysis (HMA)

The HMA is an industry best practice that is established by Chapter 4 of NFPA 855. NFPA 855 is the Standard for the Installation of Stationary Energy Storage Systems, which DNV views as the most comprehensive set of best practice guide in the industry. It is further required in accordance with Section 1207.1.6 of the 2024 IFC as a basis for increasing maximum allowable quantities (600 kWh for Li-ion ESS).

DNV reviewed the draft HMA developed for SolBank 3.0 [98]. Therefore, DNV requested the final version of HMA developed for SolBank 3.0 and DNV recommends updating this information once available. The HMA has been conducted in accordance with the 2021 International Fire Code (IFC) and the 2023 NFPA 855 guidelines. It employs a Bowtie analysis framework which includes the individual mitigative barriers, chronological pathway of threats which can lead to hazard events and potential consequences. This provides an evaluation of the effectiveness of the safety protection features installed in the energy storage system to prevent or mitigate potential battery failure scenarios which may occur. The report summarizes findings to assess the safety and overall effectiveness of barriers set in place to prevent and mitigate consequences of potential battery failure scenarios.

In general, this HMA provides adequate safety systems and mitigation measures should fault conditions result in an adverse condition. The system possesses mitigation measures and detection systems as part of the battery management system and fire and explosion protection system, which should provide notification of failure. As such, the HMA developed for SolBank 3.0 is a representative depiction of the energy storage system's failure modes and mitigating features.

5.7.5 Emergency response guide (ERG)

Emergency response guide (planning) is a crucial aspect in BESS project safety. Emergency response planning is the guidance and training that is provided to facility and first responder personnel, which accounts for the existing safety features of the BESS. The combination of system safety features and proper guidance and training provides for the safe operation and response during an emergency or safety event associated with the BESS. An Emergency Response Guide (ERG) can help inform the Project e-STORAGE's site-specific Emergency Response Plans (ERP).

DNV reviewed the draft ERP created for SolBank 3.0 [99]. The draft ERP contains purpose of ERP, fire protection & safety measures, emergency response considerations, hazards and risk evaluation, information management & resource coordination, implement response objective and emergency responses during commissioning, construction and maintenance. DNV finds that the draft ERP adequately addresses the BESS related hazards and associated action plans. In addition, DNV finds the draft ERP to be robust and in line with industry best practices with respect to emergency response planning. While DNV views the draft ERP favorably, it is a generic ERP that will require site-specific updates on a project-by-project basis. As such, DNV recommends that the draft ERP to be updated with all relevant site-specific information for each project. Typically, the ERP will be effective from the start of commissioning and the end of decommissioning periods of a Project.

5.7.6 Large Scale Fire Testing

5.7.6.1 Test Setup

The large-scale fire test was conducted using four CSI-SolBank-S-5016-2h-NA ESS containers, arranged to simulate installation conditions at the minimum manufacturer recommended spacing and evaluate fire behavior and propagation risk. The test was performed in April 2025 at the Anhui Suzhou Thermal Safety Technology National and Local Joint Engineering Research Center (CWN) and claimed to be in accordance with CSA/ANSI C800:25.

Initiating Unit A was configured as a fully populated container with 12 battery racks (6 columns), each with consisting of an BMS controller (HV box). and four battery modules. The unit also included a fire alarm system, a thermal management system (TMS), a power distribution unit (PDU), and a combiner box. Ventilation panels on the two front air inlets, as well as the left air outlet of Unit A were removed. All container doors were closed, and no active ventilation was provided. An illustration of the test layout is shown in Figure 5-17.

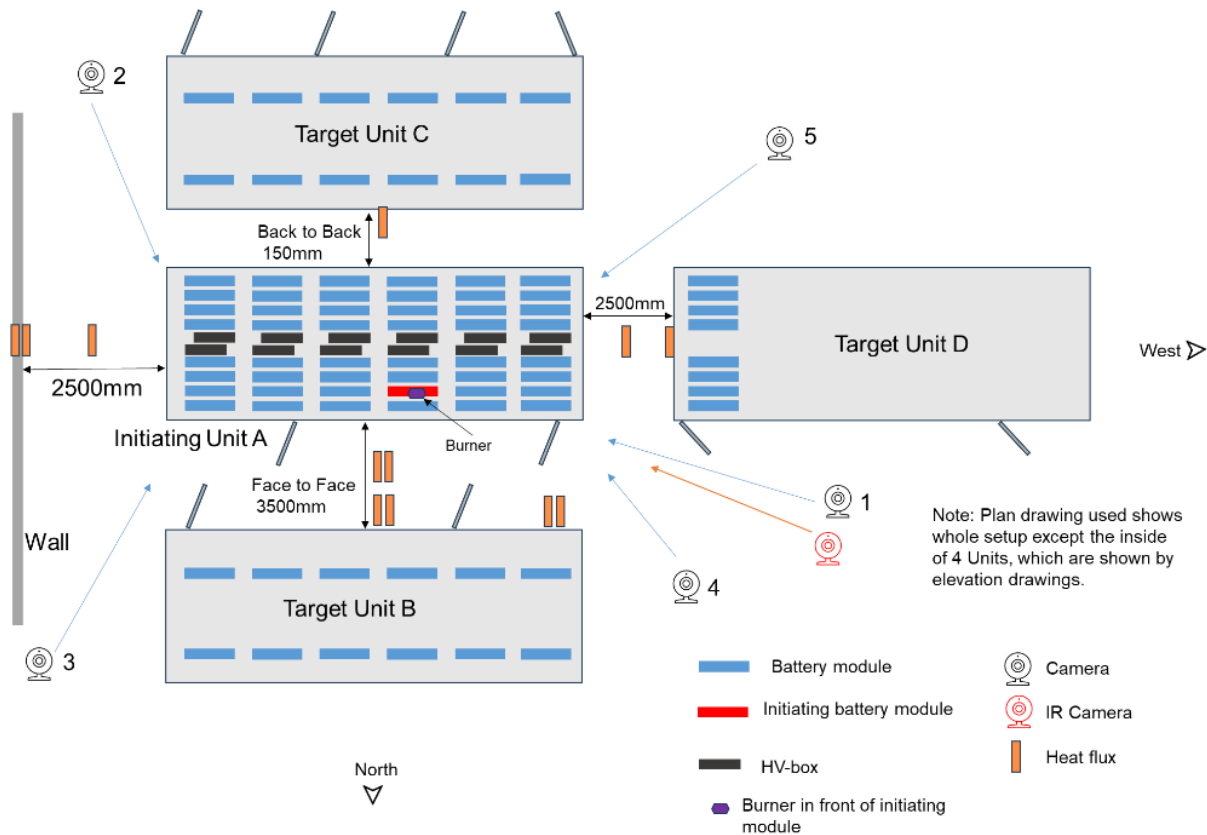


Figure 5-17 SolBank 3.0 large scale fire test layout

Target Units B, C, and D were placed around Unit A at measured distances to assess thermal exposure and potential fire propagation:

- Unit B: placed face-to-face with Unit A at a distance of 3,500 mm. It contained six battery columns, each partially populated with two modules (positions 3 and 7)
- Unit C: positioned back-to-back with Unit A at a separation of 150 mm. It mirrored the configuration of Target Unit B
- Unit D: located to the right of Unit A at a distance of 2,500 mm. Only Column 1 (closest to Unit A) of was fully populated with battery modules and remaining columns were left empty

An instrumented wall was placed to the left of Initiating Unit A, a distance of 2,500 mm, to evaluate heat flux and thermal impact on adjacent equipment. Heat flux gages were also placed in at the midpoint of the separation distances.

DNV notes that the face-to-face, end-to-end, and back-to-back spacing utilized in the test matched the minimum recommended manufacturer spacing, according to the test report.

The test report does not explicitly state the state of charge of the batteries prior to initiation of the test, however the charge graphs provided do indicate they were at a high SOC. A follow up letter from CSA provided to DNV indicates Unit A was fully charged.

The test report also indicated that Hithium 314 Ah cells were utilized in the test. DNV notes that the SolBank product uses 5 different cells and has indicated that this cell was chosen as it is anticipated that this will be the most commonly used cell in the SolBank 3.0 product. DNV notes that the test report does not indicate the SolBank 3.0 product has multiple cell options and that additional testing or simulation could be required for units utilizing a different cell OEM. e-STORAGE has indicated that they are currently working on additional modelling to support multi-cell applicability of the testing through a heat flux analysis validated by the reported test results.

5.7.6.2 Instrumentation

Thermocouples were installed at multiple locations within the initiating and target units. This included placements on the surfaces of individual cells, inside battery modules, on module covers, behind container doors, and on the internal walls. The following is a summary of thermocouple placement:

- Initiating Unit A: on the inside of the doors opposite the front of where modules are (48), front of the modules (48), two on the inside of each module (96), interior of backup initiating module (60), exterior of backup initiating module (9), interior of initiating module (60), exterior of initiating module (9) (330 total) – 304 reported
- Target Unit B: on the front face of all real modules and on the inside of the doors opposite the front of where modules would be (48) – 44 reported
- Target Unit C: on the front face of all real modules and on the inside of the doors opposite the front of where modules would be (48) – 40 reported
- Target Unit D: on the inside of the left wall opposite the center of the left face of each battery module (8) – 8 reported
- Target wall: arranged vertically (spaced 152 mm apart), aligned with the central axis of Unit A (24) – 24 reported

DNV notes that for Units A, B, and C the number of temperature results reported was lower than the number of thermocouples that were indicated to be installed. Further, DNV notes that the thermocouples in Unit C are reported to be inside the doors, when they would have been placed on the back wall, closest to the initiating Unit A.

It is further noted that Units appear to utilize different equipment in the photos provided in the report:

- Unit A appears to have deflagration vents sealed shut and no HVAC equipment installed
- Unit B appears to have no deflagration vent holes in the roof (flat roof) and appears to have HVAC systems installed
- Unit C appears to have deflagration vent panels installed and HVAC equipment installed
- Unit D photos only show the left side of the roof, but indicate no deflagration holes in the roof – might be the same as Unit B

Heat flux gauges were placed at varying heights (1,200 mm and 2,896 mm) and distances (ranging from 150 mm to 3,500 mm) to measure radiative heat transfer. Some gauges exceeded their calibrated range of 100 kW/m², indicating extreme thermal conditions, but DNV notes that this is not atypical of a severe thermal event.

The report indicated data collected included both external sensors (thermocouples, heat flux) and the onboard BMS of the target units. Limited supplemental BMS data was provided by e-STORAGE and is shown in Figure 5-18.

Visual and infrared cameras were also installed inside and outside the containers to capture fire progression.

5.7.6.3 Test Initiation

To initiate the fire, eight film heaters were installed between ten cells within a module Unit A (A-4-7). The heaters were operated until thermal runaway was achieved. Following thermal runaway of the initial cells, a pre-mixed propane/oxygen burner was directed at the front surface of the initiating module to ignite vent gases. The burner was supplied through a 100 mm x 300 mm cut-out one of the doors of Unit A, which was also used for thermocouple wires. The burner was shut off 41 minutes after ignition.

Ambient conditions at the start of the test were reported to be 16 °C (min 13 °C, max 18 °C throughout testing), with the humidity starting at 75% RH (min 75%, max 97% throughout testing). The wind direction from south, average speed 2-3 m/s (blowing towards the north and Unit B).

5.7.6.4 Results

The fire test successfully initiated thermal runaway, leading to a fully involved fire that consumed all modules in Unit A. The test report indicates the fire reached its peak intensity at 3 hours and 20 minutes after ignition, with a maximum heat release rate of 13.8 MW. Flames extended laterally up to 1.75 meters and vertically up to 7 meters. Two additional flare-ups were observed at 6 hours 07 minutes and 8 hours 14 minutes, indicating secondary combustion phases. The fire self-extinguished after 10 hours and 32 minutes without external suppression.

An overpressure event caused latching mechanism of Unit A door to fail, however the report (and provided testing photos) indicate that all doors remained closed on all units. The report also states that a second faint sound was heard, which was potentially another over pressure event. While not indicated in the report, there did not appear to be deflagration panels installed on Unit A.

The report indicates the maximum temperature of modules covers in each target unit were:

- Unit B: 141 °C
- Unit C: 39.3 °C
- Unit D: 50.9 °C

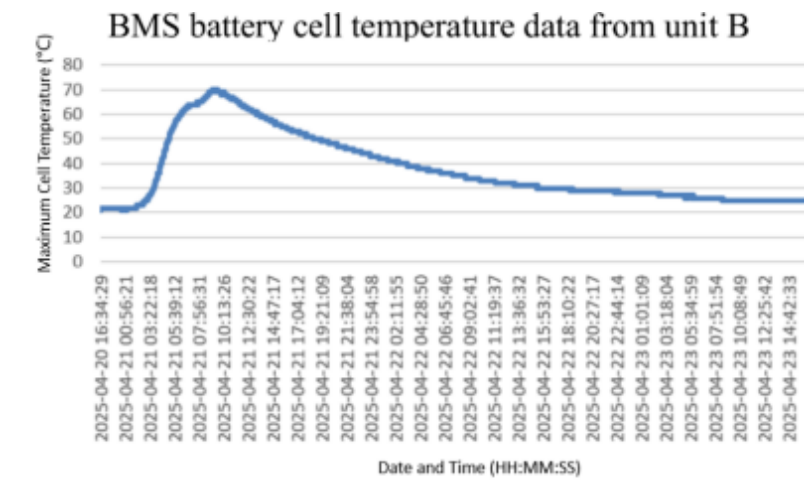
DNV notes that these temperatures were below the cell venting temperature of 204 °C (as per UL 9540A testing) for the Hithium cell tested.

The report also indicates a maximum internal target unit temperatures:

- Unit B: 168.4 °C
- Unit C: 39.3 °C
- Unit D: 92.3 °C

The maximum reported target wall temperature was 259 °C near the top of the wall, however DNV notes that the thermocouple 152 mm away from this was reported to have a maximum temperature of only 57 °C.

While not included in the fire test report, e-STORAGE provided the plot shown in Figure 5-18 which shows the maximum battery cell temperature within the lower module in Column 2 of target unit B throughout the duration of the test. It was indicated that this maximum cell temperature typically corresponded to cells 1 and 52 (module temperature sensors 1 and 28), which are located at the front of the module. The peak cell temperature of approximately 70 °C is below the cell venting temperature of 203.7 °C for the tested Hithium cell based on UL 9540A testing.



(a)



(b)

Figure 5-18 (a) BMS battery maximum cell temperature in the lower module in Column 2 of target unit B and (b) location of the module within Unit B

During the test no unit-to-unit propagation occurred, based on thermocouple temperature data. Target Units B, C, and D experienced external damage, such as scorching and discoloration, but no internal thermal damage was reported including, cell venting, or thermal runaway. Heat flux measurements in the aisle exceeded 100 kW/m², confirming severe thermal exposure. As such, DNV recommends emergency response planning incorporate egress routes well away from incident units.

The report indicates that post-test analysis confirmed that all target modules retained their structural integrity. Open circuit voltage measurements showed that cells in the target units remained charged, however this alone does not indicate a lack of cell damage. DNV notes that cell damage can still occur without fire propagation. Gas generation data indicated release of CO₂, CO, HF, and other combustion byproducts, as is typical of all battery fires.

5.7.6.5 Summary

During the testing, a CSI-SolBank-S-5016-2h-NA was successfully ignited and fully consumed by a fire. The fire did not propagate to the target units in the tested configuration; however, DNV notes that the tested configuration of the target units did not position battery modules at the top of the enclosures, where maximum temperatures would likely occur during a fire scenario. DNV also notes that the most thermally robust cell option was chosen for testing.

The tested results are considered representative for the CSI-SolBank-S-5016-4h-NA model, which shares the same structural and thermal configuration, with differences only in power-dependent components such as cooling systems and electrical controls.

DNV notes that the test report indicates no cells in the target units vented or entered thermal runaway when tested with Lithium cells. However, DNV notes that additional testing or simulations may be required when considering other battery cells.

6 INSTALLATION AND INTEGRATED SYSTEM EVALUATION

e-STORAGE provided DNV with the installation manual [100] and commissioning manual [101] of the 1500 V model of SolBank 3.0. The documents provided are comprehensive with safety details, certifications, instructions for installers, protection measures, risks, necessary equipment, connection protocols as well as post installation guidance. The installation manual also contains the layouts requirements.

6.1 On-site system integration

e-STORAGE has included safety protocols in the installation manual along with precautions needed to be followed to prevent hazards for every major step for on-site installation and integration of the BESS system. Installation site receives two separate deliveries – one consisting of a factory integrated SolBank 3.0 and the other containing Installation Parts. The pre-installation procedures for SolBank 3.0 are as follows:

- Open the wooden crates containing the equipment
- Secure lifting harness and bridge ware
 - Clearly mark the foundations where SolBank 3.0 shall be located precisely. Check the “front” side of SolBank 3.0 to ensure lift equipment setup is done correctly and place the equipment at the appropriate location
 - This lifting plan is to be developed by qualified personnel in collaboration with site safety personnel and crane operators. Remove from flatbed and set on foundation. Special care must be ensured for conduit stubs to enter SolBank 3.0 at the correct location. Conduits will penetrate special glands in SolBank 3.0 which prevent ingress of animals, insects and external debris.
 - Shim as required until level.
- Install 4 twist locks for secured lifting
- Lift and set SolBank 3.0 on the foundation
 - Secure base of SolBank 3.0 to foundation using concrete expansion bolts and anchoring hardware. For back-to-back installation, 8 twist locks are recommended (4 locks per SolBank 3.0 enclosure) but 4 locks are also acceptable in low seismic areas, one per corner with bridge locks. Additionally, the top back edge of adjacent SolBank 3.0 enclosures must be connected at the 2 locations shown in Figure 6-2. For a single-enclosure installation, it is recommended that 4 twist locks be used.
- Remove all the packaging and install the bridge ware for multi-enclosure installations.
- Final step before installation is to inspect and clean SolBank 3.0. During this step, damage checks need to be done especially for coolant distribution lines for signs of leakage. Dust and debris accumulated during transportation should be removed, especially from areas of SolBank 3.0 that are unsafe to handle during operation, using Personal Protective Equipment (PPE) always.

The detailed installation and commissioning procedure is provided in Figure 6-1 below.

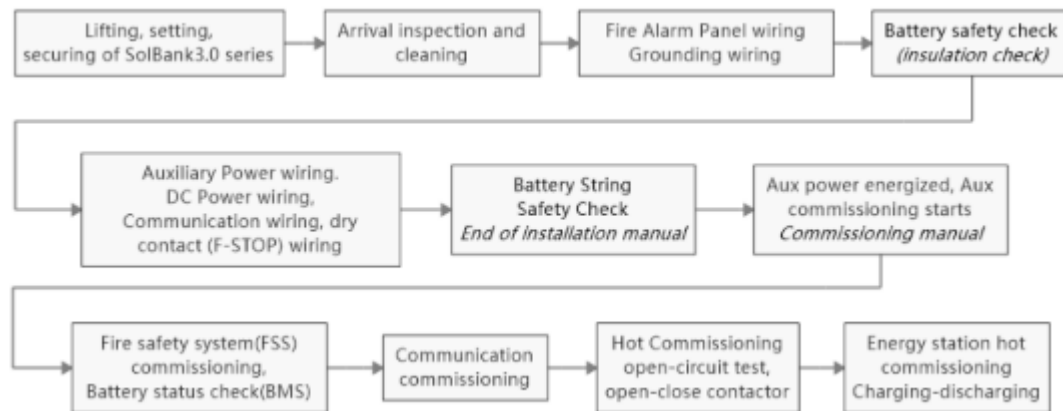


Figure 6-1 SolBank 3.0 installation and commissioning process overview

After installation, SolBank 3.0 undergoes thorough inspections of the following nature:

- Structural installation inspection: all fixing corners or bridge locks need to be in place and torque needs to be confirmed
- Electrical connection check: ground wire DC cable plugs and DC output power cable needs to be firmly installed along with check on the communication cable
- Functional check of fire protection system: lead-acid batteries installation check for the fire panel, check for the operation of fire detectors and the fan as well as appearance check of all detectors

DNV finds e-STORAGE's installation manual to include adequate details for on-site integration.

6.2 System space requirements

The dimensions of SolBank 3.0 are 6058 mm (width) by 2488 mm (depth) by 2896 mm (height). e-STORAGE recommends the clearance distances highlighted in Figure 6-2, for SolBank 3.0 installation.

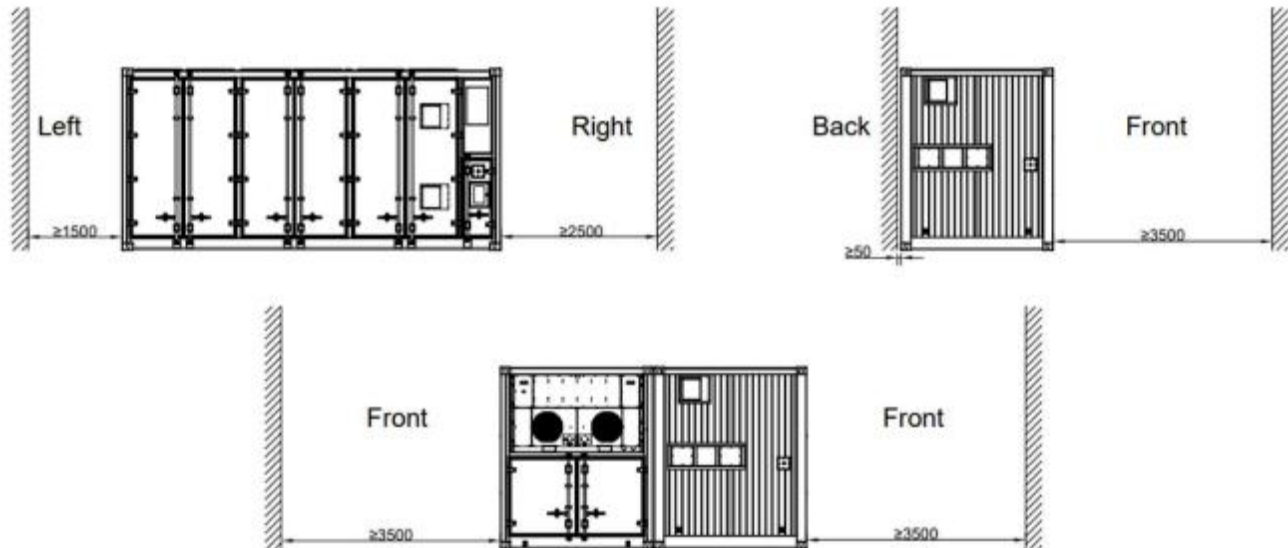


Figure SolBank 3.0 clearance distances - front view

The front side of the SolBank 3.0 enclosure must always have a clearance of 3,500 mm to ensure sufficient space for door swing, replacement of battery packs and movement of personnel. The backside should have a minimum clearance of 2,500 mm to accommodate emergency stop buttons, maintenance and operating procedures.

For left and right sides of SolBank 3.0, 1,700 mm and 2,500 mm should be maintained, respectively. This is needed for exhaust, maintenance of cooling pipes and channels along with maintenance of the chiller.

In back-to-back mounting the clearance between adjacent SolBank 3.0 should not exceed 250 mm. This separation distance is limited by bridge locks. e-STORAGE has recommended a clearance of 20 mm to 150 mm between SolBank 3.0 enclosures in the installation manual [102]. Energy Safety Response Group (ESRG) was retained on behalf of e-STORAGE to provide recommendations on the verbiage for the SolBank 3.0 enclosure separation distances [103]. ESRG confirms that SolBank 3.0 enclosures are delivered from the manufacturing facility with racks already installed. Consequently, the system is built with the separation distances tested during UL 9540A already integrated. DNV notes that the UL 9540A unit level test [104] was carried out based on 40 mm separation distance between back to wall racks. Therefore, a minimum distance of 40 mm between the racks is needed in back-to-back mounting of the enclosures. ESRG recommends, and DNV agrees, that while the UL 9540A test method is robust, it does not account for the minimum separation distances between enclosures needed to mitigate larger-scale fire or failure events, such as external flaming scenarios. It is recommended that the

manufacturer perform additional analyses to ensure that the enclosure spacing and orientations are sufficient to withstand more severe failure events beyond those tested under UL 9540A conditions.

In addition, SolBank 3.0 features a mirrored design, where the container is designed as a complete mirror, with the container fan relocated from the rear to the door side, as shown in Figure 6-3. Furthermore, chiller and the liquid cooling piping also adopts a mirrored layout, as illustrated in Figure 6-4. The design also includes detailed clearance specifications options for both single and split bus configurations, and consideration for transportation operations. Refer to Figure 6-5 for mirror design clearances for mirror design. DNV notes that there are no changes to the product materials, key components, performance, or functionality. DNV considers SolBank 3.0 mirror design favorably.

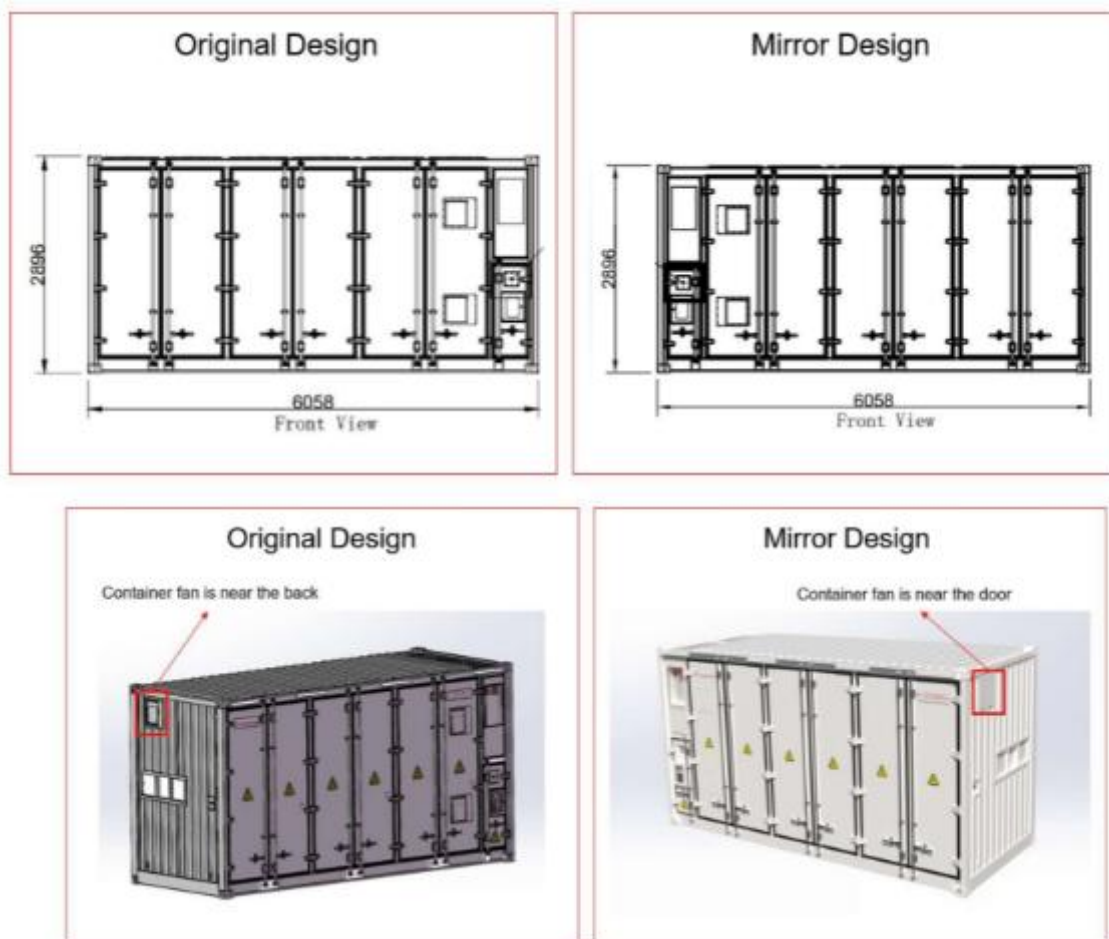


Figure 6-3 The container and container fan mirror design

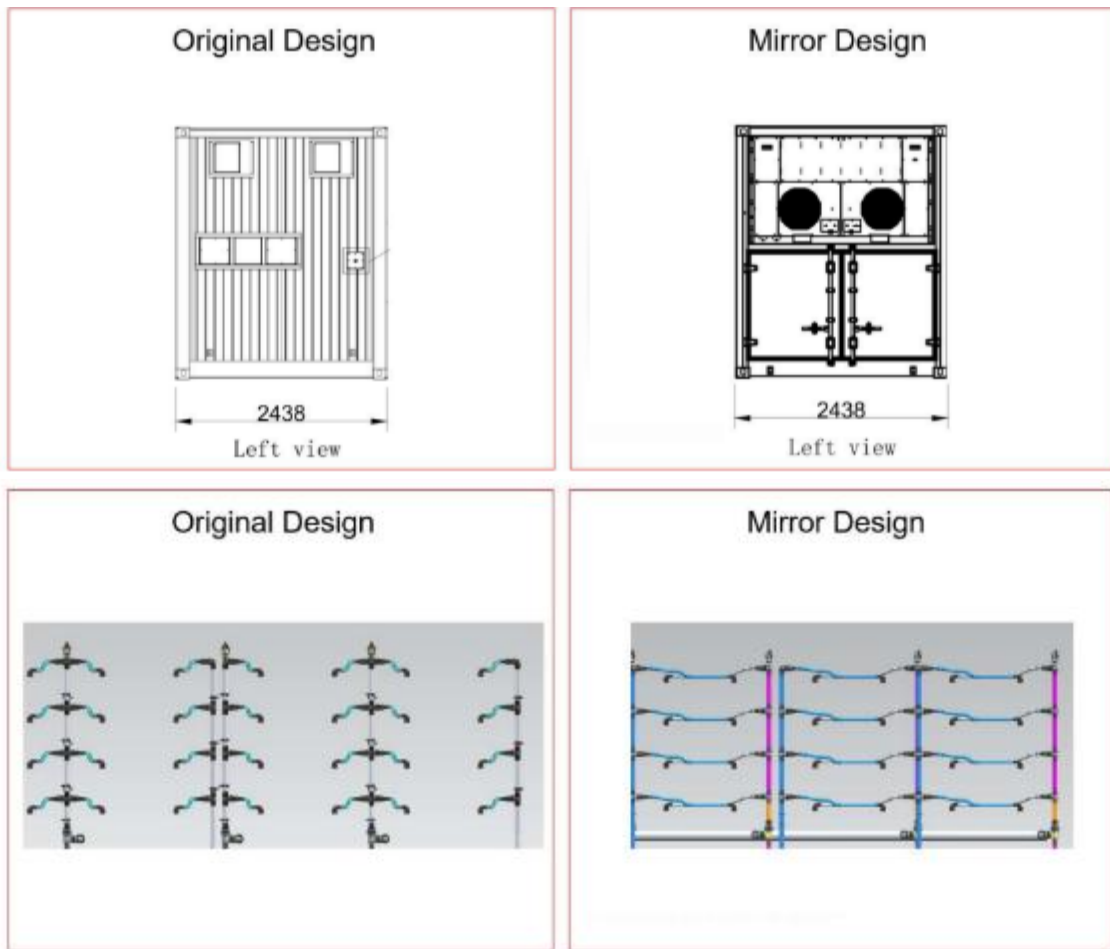


Figure 6-4 Chiller and liquid piping mirror design

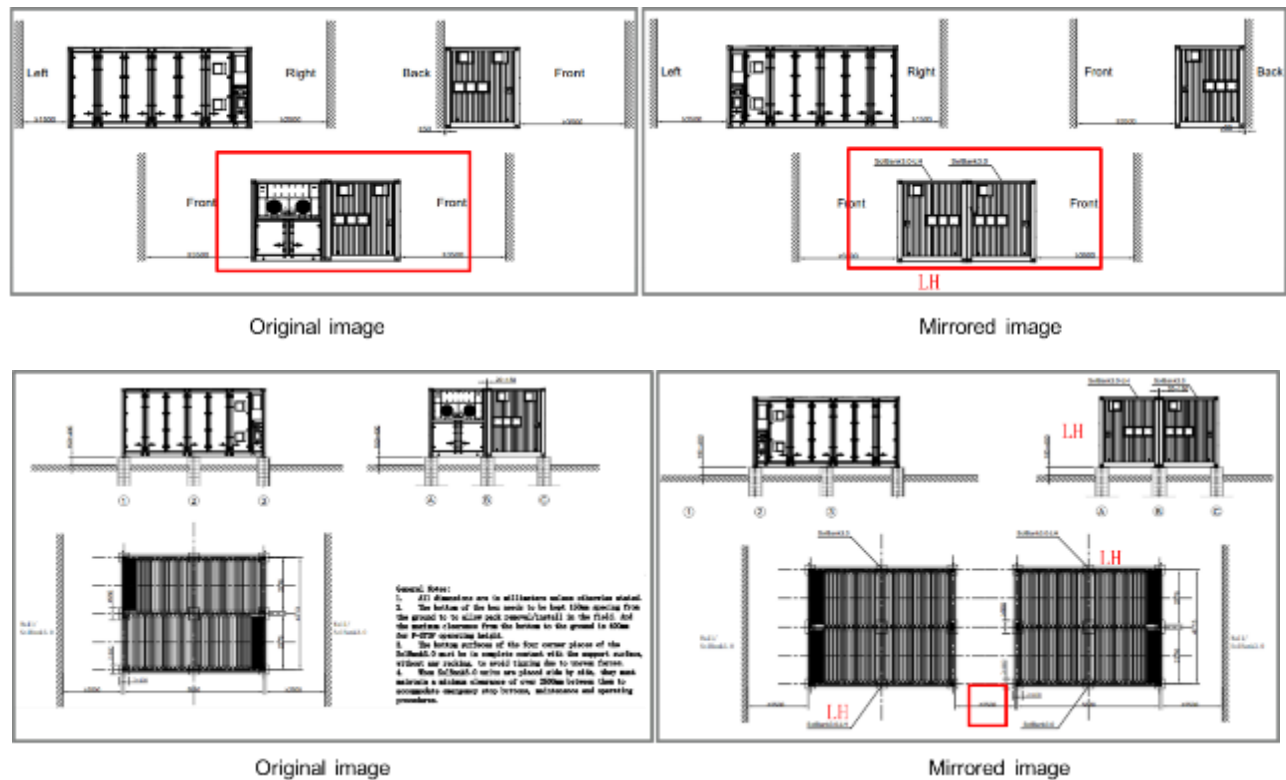


Figure 6-5 SolBank 3.0 mirror design clearances

6.3 Site requirements

For successful installation, the following preparations measures must be carried out:

- Foundations must be properly cured
- Foundation dimensions must reflect SolBank 3.0 dimensional requirements and those indicated in the site IFC civil documentation
- Foundation levelness is within required tolerances - the flatness after levelling does not exceed 0.002L
- Power, communication, and signal cable conduit stub-ups are located within required tolerances and properly labelled
- Grounding grid stingers are installed and located within required tolerances and ground grid has been properly tested

DNV finds the required procedures to be in line with industry norms.

6.4 Functional manuals

6.4.1 User manual

DNV reviewed the SolBank 3.0 user manual [105] and found details on all the key features, components, controls along with startup and shutdown operations.

The user manual specifies various modes of operation: operational, idle, eco, failure and debug. Additionally, it provides a pre-operation checklist procedure for safety, operational readiness and functionality. The user manual also describes the initial startup and system shutdown procedures as follows:

- Initial system startup: this process needs to be done after initial system commissioning, maintenance activities requiring full system shutdown and component isolations or periods of extended system storage. A 13-step procedure is followed during system commissioning.
- System shutdown:
 - Emergency system shutdown: SolBank 3.0 can be shut down remotely or locally depending on the emergency on site. Careful steps and safety procedures are defined for this action.
 - Partial system shutdown: for inspection or maintenance work on the power conversion system (PCS) or upstream devices, the equipment can be partially shutdown by following a careful 8-step process listed in the user manual.
 - Full system shutdown: typically to perform comprehensive maintenance, this step is done by deenergizing all components. However, e-STORAGE mentions that the battery pack cannot be powered off. The battery pack's voltage can be reduced by isolating the battery cells by unplugging the battery pack power connector.

A special detail on storage conditions is defined for SolBank 3.0. Adequate details on auxiliary power availability, storage condition and temperatures for storage conditions are provided.

DNV finds that adequate information and details regarding SolBank 3.0 has been provided in the user manual.

6.4.2 Maintenance manual

The maintenance manual includes information on maintenance tools, schedules, replacement work and detailed maintenance procedures. Some of the notable maintenance cycles are mentioned in Table 6-1 below.

Table 6-1 Maintenance list

No.	Maintenance Item	Maintenance Period
1	Reporting and Diagnostics: Technical support and fault diagnosis (Corrective Maintenance)	As required
2	Reporting and Diagnostics: Inspection, maintenance reports and recommendations (Corrective Maintenance)	Monthly
3	Reporting and Diagnostics: Data server connectivity check (Corrective Maintenance)	Monthly
4	Reporting and Diagnostics: Inspect battery running status, provide operating recommendations and maintain battery (Corrective Maintenance)	Monthly
5	Thermal Management System: Thermal management system inspection; Thermal management system maintenance; Clean Filters by rinsing with Water; Electric Heater - Dust accumulation on the coil, signs of overheating on the heater frame, traces of water or rust on the electric heater control box	Semi-Annual
6	Battery: Visual inspection of all electrical terminations using thermal imager	Semi-Annual

No.	Maintenance Item	Maintenance Period
7	Thermal Management System: Coolant tester visual inspection	Annual
8	General: System configuration check	Annual
9	DMC/Junction Box/ Auxiliary System/ Miscellaneous: Auxiliary equipment maintenance and inspection; enclosure dust removal; Inspect cable entry, grounding, sealing, dust removal; Critical sensor calibration check; Maintenance	Annual
10	Fire Safety System: Fire alarm and detection system inspection; Fire alarm and detection system maintenance; Fire suppression System Inspection	Annual
11	Battery: Set battery maintenance (system check, cell balancing); Battery cable, appearance, grounding, dust removal; Inspect battery management system alarms	Annual
12	UPS Battery (Periodic Replacement)	4 years
13	SPD (Periodic Replacement)	5 years
14	Warning label (Periodic Replacement)	5 years
15	Fan (Periodic Replacement)	8 years
16	Chiller (Periodic Replacement)	10 years

The maintenance plan also includes activities for auxiliary system maintenance, capacity test, torque requirements and SolBank 3.0 check list. DNV notes that the information in the maintenance manual is sufficient and aligns with expectations.

6.4.3 Commissioning manual

DNV reviewed the commissioning manual [101] provided by e-STORAGE and finds the document to include the important aspects needed to successfully commission the BESS system. The manual included a pre-operation checklist for successful commissioning, tools needed for debugging, an overview of the system, forms to ensure complete tests of commissioning and steps to integrate SolBank 3.0 internet protocol address.

SolBank 3.0's commissioning manual lists the following steps:

- Preparing for debugging: preparing for debugging with safety procedures in place to remove static
- Field installation confirmation: verification to be done for field installation by confirming battery wiring and harnessing
- Cabling for battery strings in series: batteries should be connected in series after checking the cabin voltage
- Insulation and safety tests for battery strings: verify insulation resistance by conducting tests on each battery string. This needs to be done before the battery cables are connected.
- Power on the auxiliary power supply: detailed steps are provided to ensure the UPS output voltage is at 220 V AC
- Start the control system: steps are provided on how to turn on power supplies and to check the operating status of devices such as BMS, fire control, water immersion sensor, temperature and humidity sensors
- Master-Slave mode commissioning: steps for connecting with Modbus and function verification steps are provided in detail
- SolBank 3.0 function verification: e-STORAGE has provided complete steps to start the control system with internet protocol setup

e-STORAGE also provided a complete debugging flow chart shown in Figure 6-6.

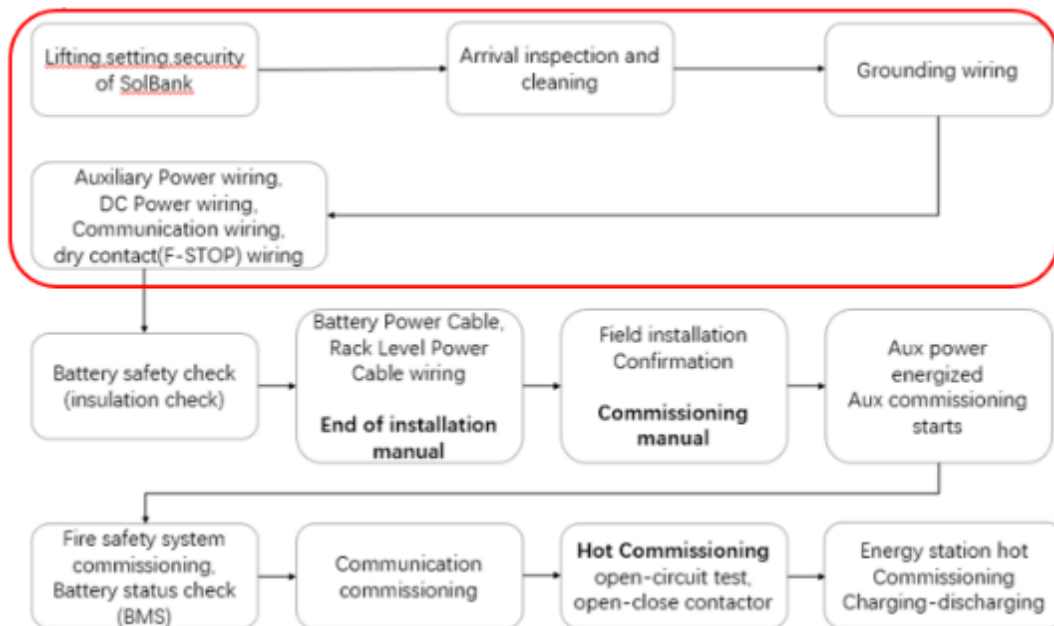


Figure 6-6 Debugging process for SolBank 3.0

DNV finds the commissioning manual to be satisfactory.

6.5 Decommissioning and end-of-life processes

DNV reviewed SolBank's decommissioning manual, which provides an overview of the processes and procedures required to decommission a SolBank 3.0 BESS. Topics covered include pre-decommissioning inspections and checks, equipment disassembly, and removal.

Pre-decommissioning procedures include a preliminary inspection to ensure that the battery SOC range complies with local transportation safety regulations, batteries are not leaking or swelling, and no leakage of coolant has occurred. A checklist is also provided to ensure all safety guidelines and lock-out-tag-out (LOTO) procedures are adhered to, and that all permits have been obtained.

Figure 6-1 below provides an overview of the SolBank 3.0 disassembly process. These steps must be followed sequentially and must be performed by qualified personnel. Upon LOTO, the string DC power of the BESS shall be disconnected via the rotary disconnect switches. The battery packs are then electrically disconnected from the cables and connections, after which the external interface wiring is disconnected, which includes the auxiliary power cable, signal wires, communication cable, DC cable, and then grounding. Upon completion of the prior procedures, the BESS is lifted and physically removed from the facility.

DNV considers the decommissioning approach to be reasonable and in line with typical expectations.

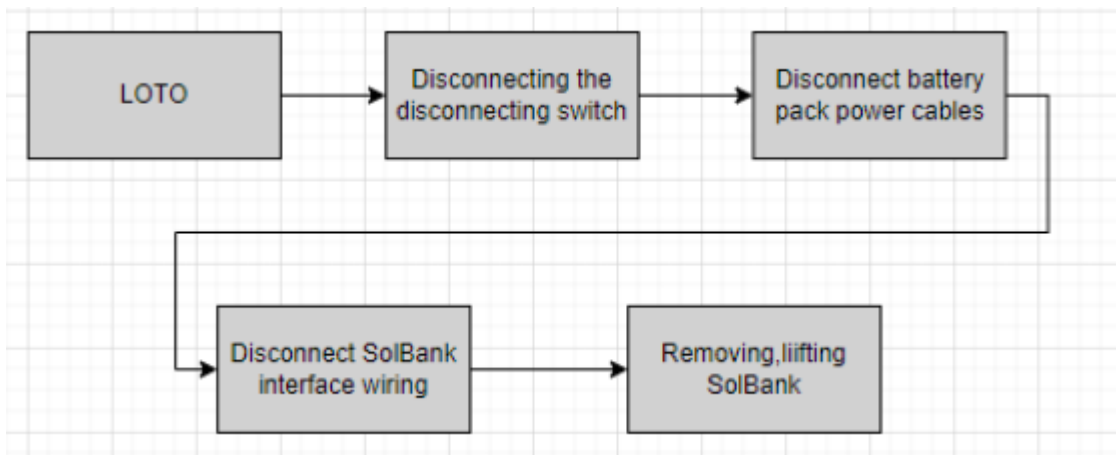


Figure 6-7 SolBank 3.0 disassembly process overview

e-STORAGE shared the SolBank 3.0 Safety Manual [106], which states observations and procedures for emergency system shutdowns as well as fire alarm response.

In the event of an emergency on site, SolBank 3.0 can be shut down locally, or remotely. SolBank 3.0 alarms will be forwarded to remote operations, and the respective personnel can shut down SolBank 3.0 if determined to be necessary. If safe to approach SolBank 3.0, the F-stop button located on either end of SolBank 3.0 can be pushed if remote shutdown is not possible. When the F-stop is pushed, the SolBank 3.0 BMSs will disconnect all battery strings from the main system bus, thereby stopping all charging and discharging. Simultaneously, the plant PCS will shut down if properly configured to do so. If indications of a fire within a SolBank 3.0 exist, such as smoke emanating from the SolBank 3.0, or activation of the fire alarm strobe, it is recommended to immediately evacuate the area and maintain a safe perimeter, and system shut-down should be attempted remotely.

In the event of a fire, or indication of a fire within a SolBank 3.0, e-STORAGE recommends that first responders establish a secure perimeter, monitor, and approach only when determined safe to do so by an incident commander or other qualified authority. No direct suppression tactics are advised by e-STORAGE. In the absence of a justified reason to enter the site (i.e. entrapment of personnel), it is advised that emergency first responders not take direct action to suppress the fire. A communication link should be established with the remote system operator to obtain data regarding system status if available. Battery/cell status, temperature, and voltage trends should be observed to quantify scope of event and conditions within the affected and adjacent SolBank 3.0s.

Damaged cells/packs can result in the release of combustible vapors, and propagation of thermal runaway reactions to neighboring packs. The damaged battery pack must be isolated with a space of 5 meters free of inflammable and explosive materials. A damaged battery pack should be monitored during storage for evidence of smoke, flame, leakage of electrolyte or signs of heat. If full-time monitoring of the damaged product is not possible (e.g., during extended storage), the damaged product should be moved to a safe storage location. A safe storage location for a damaged battery pack will be free of combustible materials and accessible only by trained professionals. A damaged battery pack must not be stored adjacent to undamaged products.

Batteries at the end of their service life should be disposed of or recycled in accordance with local, state, and federal regulations, which vary based on jurisdiction. Lithium-ion batteries are regulated as Class 9 Miscellaneous dangerous goods (also known as “hazardous materials”) pursuant to the International Civil Aviation Organization (ICAO) Technical Instructions



for the Safe Transport of Dangerous Goods by Air, International Air Transport Association (IATA) Dangerous Goods Regulations, the International Maritime Dangerous Goods (IMDG) Code, European Agreements concerning the International Carriage of Dangerous Goods by Rail (RID) and Road (ADR), and applicable national regulations such as the USA's hazardous materials regulations. These regulations contain very specific packaging, labeling, marking, and documentation requirements. The regulations also require that individuals involved in the preparation of dangerous goods for transport be trained on how to properly package, label, mark and prepare shipping documents.

DNV considers e-STORAGE's contingency planning for removal, transportation, and disposal of the BESS to be in line with typical industry expectations.

7 MANUFACTURING AND QUALITY EVALUATION

DNV reviewed e-STORAGE's manufacturing and quality systems associated with production of SolBank 3.0. Table 6-1 summarizes major BESS components and their OEM or contract manufacturing (CM).

Table 7-1 SolBank 3.0 major component manufacturer summary

Component	OEM	Location
Battery cells	Hithium	Xinyu City, China/Xiamen, China
Battery cells	e-STORAGE	Dafeng, China
Battery cells	EVE	Jingmen, China
Battery cells	Cornex	Xiaogan City, China
Battery cells	Sunwoda	Deyang City, China
Battery modules/packs	e-STORAGE	Suzhou and Dafeng, China
Enclosure	e-STORAGE	Suzhou and Dafeng, China

7.1 Cell quality and manufacturing

The following sections review the quality and manufacturing processes associated with the development of battery cells for SolBank 3.0.

7.1.1 Quality systems evaluation

The cells used in SolBank 3.0 are provided by different suppliers Hithium, EVE, Cornex, Canadian Solar Co. LTD, and Sunwoda.

Xiamen Hithium Energy Storage Technology Co. Ltd's management system is built based on the following standards: ISO 9001:2015 (quality system) [107], ISO 14001:2015 (Environmental system) [108], ISO 45001:2018 (occupational health and safety system) [109]. Table 7-2 provides a summary of Hithium's manufacturing facility's certifications.

Table 7-2 Hithium cell manufacturing facility quality certifications

Standard	Holder	Location	Number	Validity
ISO 9001:2015	Xiamen Hithium Energy Storage Technology Co. Ltd	Xiamen, China	CN22/30650	09 Feb 2026 until 08 Feb 2029
ISO 14001:2015	Xiamen Hithium Energy Storage Technology Co. Ltd	Xiamen, China	CN25/00006021	1 Dec 2025 until 30 Nov 2028
ISO 45001:2018	Xiamen Hithium Energy Storage Technology Co. Ltd	Xiamen, China	CN25/00006022	1 Dec 2025 until 30 Nov 2028

EVE's management system is built based on ISO 9001:2015 (quality system), ISO 14001:2015 (Environmental system), ISO 45001:2018 (occupational health and safety system) [110] [111] [112].

Table 7-3 provides a summary of EVE's manufacturing facility's certifications.

Table 7-3 EVE cell manufacturing facility quality certifications

Name	Holder	Location	Number	Validity
ISO 9001:2015	EVE Power Co., Ltd	Jingmen, China	449788-2021-AQ-RGC-RvA	16 Jun 2024 until 15 Jun 2027
ISO 14001:2015	EVE Power Co., Ltd	Jingmen, China	203088-2016-AE-RGC-RvA	17 Nov 2025 until 14 Nov 2027
ISO 45001:2018	EVE Power Co., Ltd	Jingmen, China	203087-2016-ASA-RGC-RvA	17 Nov 2025 until 14 Nov 2027

Cornex's management system is built based on ISO 9001:2015 (quality system), ISO 14001:2015 (Environmental system), ISO 45001:2018 (occupational health and safety system) [113] [114] [115]. Table 7-4 provides a summary of Cornex's manufacturing facility's certifications

Table 7-4 Cornex cell manufacturing facility quality certifications

Name	Holder	Location	Number	Validity
ISO 9001:2015	Cornex New Energy Co. LTD.	Xiaogan City, China	12 100 67891/01 TMS	15 July 2024 until 14 July 2027
ISO 14001:2015	Cornex New Energy Co. LTD.	Xiaogan City, China	00123E31709R0L/4200	28 April 2024 until 15 May 2026
ISO 45001:2018	Cornex New Energy Co. LTD.	Xiaogan City, China	00123S31404R0L/42000	29 April 2024 until 16 May 2026

CSI's management system is built based on ISO 9001:2015 (quality system), ISO 14001:2015 (Environmental system), ISO 45001:2018 (occupational health and safety system) [116] [117] [118]. Table 7-5 provides a summary of Canadian Solar Co. LTD's manufacturing facility's certifications

Table 7-5 Canadian Solar Co. LTD cell manufacturing facility quality certifications

Name	Holder	Location	Number	Validity
ISO 9001:2015	Canadian Solar Co. LTD	Dafeng, China	0100029101	6 August 2024 to 8 August 2027
ISO 14001:2015	Canadian Solar Co. LTD	Dafeng, China	01104029101	24 April 2025 to 23 April 2028
ISO 45001:2018	Canadian Solar Co. LTD	Dafeng, China	01213029101	24 April 2025 to 23 April 2028
ISO 50001:2019	Canadian Solar Co. LTD	Dafeng, China	00524En4012R0M	22 August 2024 to 8 August 2027

Sunwoda's management system is built based on ISO 9001:2015 (quality system) and ISO 14001:2015 (Environmental system) [119] [120]. Table 7-6 provides a summary of Sunwoda's manufacturing facility's certifications.

Table 7-6 Deyang Sunwoda New Energy Co. LTD. cell manufacturing facility quality certifications

Name	Holder	Location	Number	Validity
ISO 9001:2015	Deyand Sunwoda New Energy Co. LTD.	Deyang City, China	050722001C	7 July 2023 to 6 July 2026
ISO 14001:2015	Deyand Sunwoda New Energy Co. LTD.	Deyang City, China	00524E756R0M	8 August 2024 to 7 August 2027

Name	Holder	Location	Number	Validity
ISO 45001:2018	Deyand Sunwoda New Energy Co. LTD.	Deyang City, China	00524S3757R0M	8 August 2024 to 7 August 2027

7.2 Battery pack and container quality and manufacturing (Suzhou)

The following sections present an assessment of the quality management framework and manufacturing processes for SolBank 3.0, covering activities from battery pack assembly to container integration.

On 16 January 2025, DNV visited e-STORAGE's Suzhou factory, located at No. 348 Lushan Road, SND, Suzhou, Jiangsu, China. The visit focused on the evaluation of the quality management system and manufacturing quality controls.

The factory began production of SolBank 1.0 in 2022 and initiated production of SolBank 3.0 in October 2024. In 2024, the nameplate production capacity was 1.489 GWh, with actual production reaching approximately 300 MWh. For 2025, the cumulative nameplate capacity was expected to reach 6.26 GWh, of which 2.74 GWh was attributed to SolBank 3.0 production.

7.2.1 Quality systems evaluation

The CSI BESS integration factory has obtained international certifications ISO 9001, ISO 14001, and ISO 45001, aligning with typical industry practices. See Table 7-7 for summary.

Table 7-7 CSI BESS integration facility (Suzhou, China) quality certifications

Name	Holder	Location	Number	Validity
ISO 9001:2015	CSI Energy Storage (Suzhou) System Integration Co., LTD	Suzhou, Jiangsu, China	011002532651/04	05 August 2027
ISO 14001:2015	CSI Energy Storage (Suzhou) System Integration Co., LTD	Suzhou, Jiangsu, China	01104029101/29	23 April 2028
ISO 45001:2018	CSI Energy Storage (Suzhou) System Integration Co., LTD	Suzhou, Jiangsu, China	01213029101/29	23 April 2028

7.2.2 EHS

During a recent audit of the Environmental, Health, and Safety (EHS) hazard identification process, DNV notes that the hazard identification form had not been signed off at the time of the site visit. CSI clarified that the hazard identification form would be revised and is approved annually by each department.

To address this issue, CSI has implemented the following measures:

- Timely summarization and sign-off: Following the annual update of the hazard identification form at the beginning of the year, the form will be promptly summarized and formally approved.
- Standardization of documentation approval: CSI will ensure that all target indicators, management review reports, emergency drill plans, and annual inspection plans are signed and approved in a timely manner.

CSI provided signed and approved EHS control documents as evidence, as shown in Figure 7-1.

注: 1. L: 事故发生的可塑性; E: 故障原因的可塑性; C: 事故产生的后果; D: 风险等级判定, $L \times E \rightarrow D$
2. $D \geq 320$, 危险程度: 1-IV 级; $320 > D \geq 160$, 危险程度: 2-III 级; $160 > D \geq 80$, 危险程度: 3-II 级; $D < 80$, 危险程度: 4-I 级

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10.02	10.03	11	10.002	10.01	10.02	10.03	10.04	10.05	10.06	10.07	10.08	10.09	10.10	10.11	10.12	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100
10.02	10.03	11	10.002	10.01	10.02	10.03	10.04	10.05	10.06	10.07	10.08	10.09	10.10	10.11	10.12	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100

姓名: 郭政通 日期: 郭政通

The supplier audit checklist should be comprehensive, with results documented and supported by evidence. During the spot check audit, the VDA 6.3 template was utilized; however, no supporting audit evidence was provided for the items marked as “green light.”

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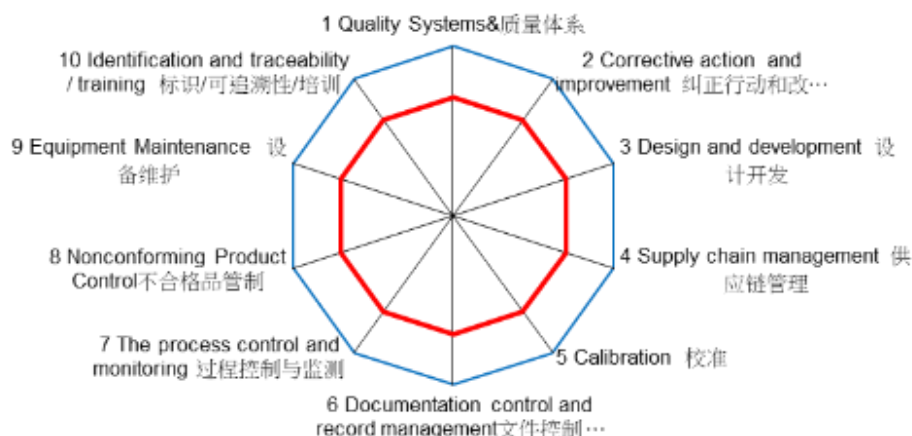
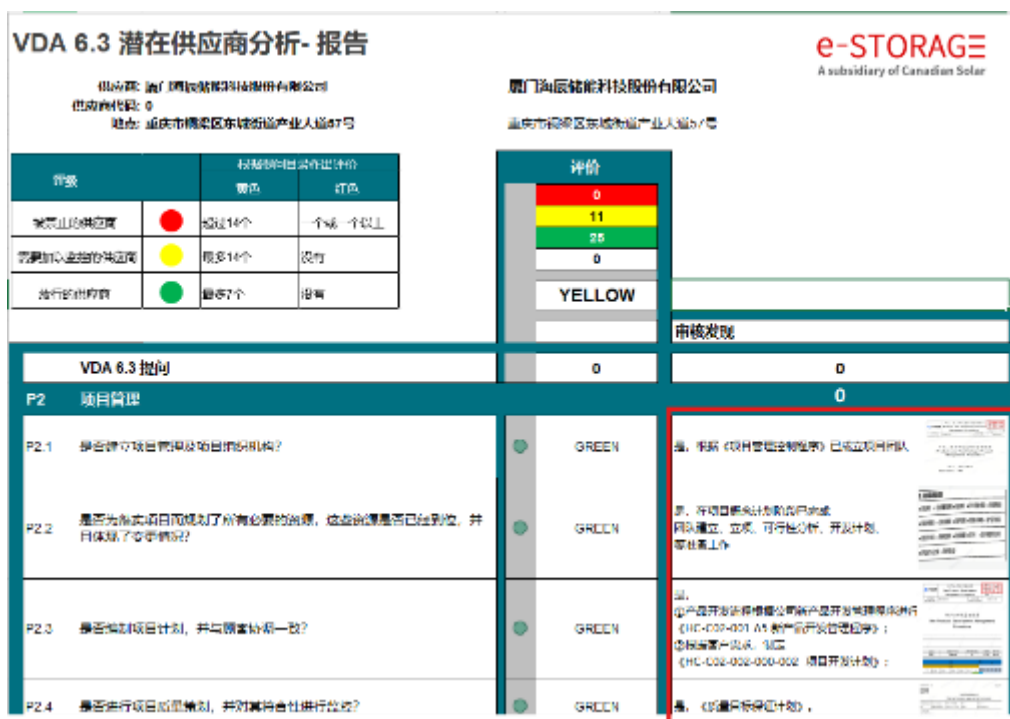


Figure 7-2 FR-QA006 quality system form A0

CSI performed the supplier audit based on the evaluation form. The results and ratings are documented with supporting evidence as shown in Figure 7-3.



序号	缺陷描述/问题点	缺陷等级	缺陷数量	缺陷描述
1	项目管理制度	红色	0	一个及以上
2	项目管理制度	黄色	11	没有
3	项目管理制度	绿色	0	没有

VDA 6.3 提问	0	0
P2 项目管理	0	0
P2.1 是否建立项目管理制度及项目组织机构?	GREEN	是, 根据《项目管理手册》已建立项目团队
P2.2 是否为客户项目制定了必要的资源, 这些资源是否已经到位, 并且保持了更新?	GREEN	是, 在项目启动计划阶段已制定项目计划, 包括: 项目计划、里程碑、可行性分析、开发计划、测试计划等
P2.3 是否编制项目计划, 并与客户要求一致?	GREEN	是, 项目计划编制符合客户要求并经过客户确认
P2.4 是否进行项目资源规划, 并对资源进行分配?	GREEN	是, 《项目资源规划》

Figure 7-3 Screenshot for supplier audit evidence

7.2.4 Warehouse management

During the audit, it was identified that the warehouse lacked a temperature-controlled storage area for electronic materials, which require strict environmental control. According to the existing "Material Storage Specifications," the required storage conditions are a temperature range of 10 °C to 28 °C and relative humidity below 70%.

As a corrective measure, CSI is currently implementing temperature and humidity monitoring in accordance with the documented requirements (see Figure 7-4). In addition, the factory will establish a dedicated enclosed warehouse area with independent temperature and humidity controls.



The new warehouse includes a dedicated internal storage area for critical materials such as batteries, equipped with temperature and humidity monitors that record data on a daily basis, as shown in Figure 7-5.



During the audit, it was identified that the warehouse's on-site management requires improvement, particularly in the effective implementation of first-in, first-out (FIFO) practices. Areas of concern include the physical arrangement of materials by date and the need to clearly define whether material batch labeling should be applied at the outer packaging level or at the pallet level.

CSI utilizes an SAP system with a Warehouse Management (WM) module to manage material storage and movements. FIFO control is implemented through system-controlled batch selection at the time of material issuance, rather than through sequencing of material storage locations. The CSI planning department issues materials by selecting batches within the system in accordance with the FIFO principle. Materials are managed and packaged at the pallet level, with each pallet individually labeled. After each material issuance, pallet labels are updated and information is recorded in the system.

To support this process, the warehouse team provided supplementary evidence, including a warehouse management system (WMS) screenshot and a written explanatory statement (see Figure 7-6), which demonstrate how pallet and box numbers are managed and how FIFO logic is applied during material movements [121]. During routine operations, if an incorrect batch is issued from the warehouse to the production line that does not comply with FIFO requirements, the system automatically generates an alarm and blocks the transaction to prevent FIFO non-compliance.



物料	物料描述	批次	非限制使用的库存	质量检验	已冻结	单位
81000009	IO扩展板/艾莫迅MD200-IO16R/塑料/	3WJ2511801	1	0	0	PC
	IO扩展板/艾莫迅MD200-IO16R/塑料/	3WJ2511802	1	0	0	PC
	IO扩展板/艾莫迅MD200-IO16R/塑料/	3WJ2511803	1	0	0	PC
	IO扩展板/艾莫迅MD200-IO16R/塑料/	3WJ2511806	1	0	0	PC
	IO扩展板/艾莫迅MD200-IO16R/塑料/	3WJ2511807	1	0	0	PC
	IO扩展板/艾莫迅MD200-IO16R/塑料/	3WJ2511808	1	0	0	PC
	IO扩展板/艾莫迅MD200-IO16R/塑料/	3WJ2512302	1	0	0	PC
	IO扩展板/艾莫迅MD200-IO16R/塑料/	3WJ2512303	1	0	0	PC
	IO扩展板/艾莫迅MD200-IO16R/塑料/	3WJ2512304	1	0	0	PC
			9	0	0	PC

Figure 7-6 Warehouse and SAP screenshot

7.2.5 FMEA

CSI has mitigated safety risks in its system integration process by conducting a Failure Modes and Effects Analysis (FMEA) in accordance with applicable industry standards. The company has defined FMEA scoring criteria to evaluate key risk indicators: severity (S), occurrence (O), and detectability (D). However, based on the site visit, certain severity ratings require further clarification. For example, the severity ratings assigned to failure modes like pseudo soldering and explosive soldering were initially set to 4, despite the potential to result in significant quality impacts. These ratings therefore required reassessment and updates. CSI provided the following corrective action plan:

- Update the PFMEA in alignment with the DFMEA and FMEA scoring criteria defined by R&D.
- Organize FMEA training as needed.

The updated PFMEA reflects increases severity ratings for pseudo soldering and explosive soldering, revised to 8 and 7, respectively.

During the on-site audit, it was identified that production activities started in October, whereas the controlled release date of the applicable SOPs was in November. As a result, no formally controlled SOPs were available to guide production activities during October through November. CSI explained that SolBank 3.0 was in the trial production phase during this period and that production was conducted using signed and approved temporary documents, which had not been released through the OA document system. As a result, the controlled SOP version in the OA system was not updated to reflect the temporary documents in use.

To address this issue, controlled documents in the OA system are required to be updated based on the approved temporary document versions. For products in trial production intended for shipment, the relevant SOP must be controlled and released in the OA system prior to the start of production, with oversight from the Design Quality Engineer (DQE).

7.2.6 Manufacturing evaluation

DNV's site visit was focused on two elements:

- Overall quality control review
- Production process characterization and production process quality control for module and pack and ESS Container

7.2.6.1 Incoming quality control (IQC) test

CSI maintains a dedicated facility for IQC testing to ensure materials undergo inspection prior to release into production (see Figure 7-7). DNV conducted random audits of IQC procedures and equipment calibration records, confirming that formal IQC procedures are in place and implemented. However, it was identified that the calibration label for the feeler gauge had expired. This issue occurred because CSI recorded the calibration validity period as one year, whereas the associated calibration certificate was valid for only six months. Corrective measures implemented include:

- The user department was instructed to immediately stop using the affected instrument.
- Recalibration was arranged and completed by 24 January 2025, with the correct validity period indicated.
- The user department was notified to verify instrument calibration status prior to use and to conduct monthly on-site checks of measuring instruments.

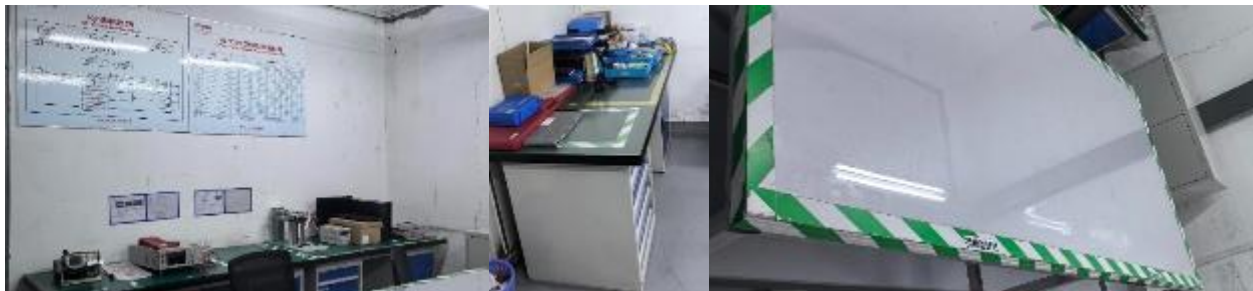


Figure 7-7 Incoming materials inspection room

During the site visit, it was identified that the IQC area is limited in size and does not have a designated space for non-conforming products. CSI plans to implement measures to divide the IQC area into clearly defined zones for "Pending Inspection," "Inspected," and "Non-Conforming Products." In addition, for IQC samples, the "Energy Storage Sealed Sample Management Guidelines" have been established, and a dedicated sample room has been planned for the new facility.

During the review, it was identified that the environmental requirements for Cell Contactor System (CCS) NTC temperature inspection (23 °C to 27 °C) were not met, as inspections were conducted under general room-temperature conditions. CSI's analysis determined that the NTC resistance of the CCS assembly varies with temperature and that a resistance–temperature (R-T) table is available to define resistance standards at different temperatures. However, the SAP system does not support dynamic adjustment of resistance ranges and currently only maintains acceptance values for the 23 °C to 27 °C range.

To address this issue, CSI implemented the following measures:

- Updated the incoming inspection SIP to specify: “At room temperature, use a multimeter to test the NTC contacts. Record the ambient temperature and resistance value electronically and compare the results with the R-T table to determine conformity.”
- Updated the relevant SAP inspection item descriptions.
- Created an electronic spreadsheet to record NTC resistance values for each batch.

CSI has formally updated the Incoming Inspection SIP to include the following requirements: under room-temperature conditions, a multimeter is used to measure the resistance of the NTC contacts; the ambient temperature during testing is recorded; the measured resistance values are documented electronically; and the results are compared against the R-T table to determine compliance accordingly.

DNV concludes that CSI is capable of promptly identifying root causes and implementing targeted improvement measures, supported by appropriate documentation.

7.2.6.2 Module and pack assembly

The automatic assembly line for prismatic cell modules includes key processes such as module assembly and pack assembly. CSI’s module assembly process utilizes automatic assembly and Automated Guided Vehicles (AGVs) for material logistics, aligning with common industry practices. The module and pack assembly processes are illustrated in Figure 7-8.

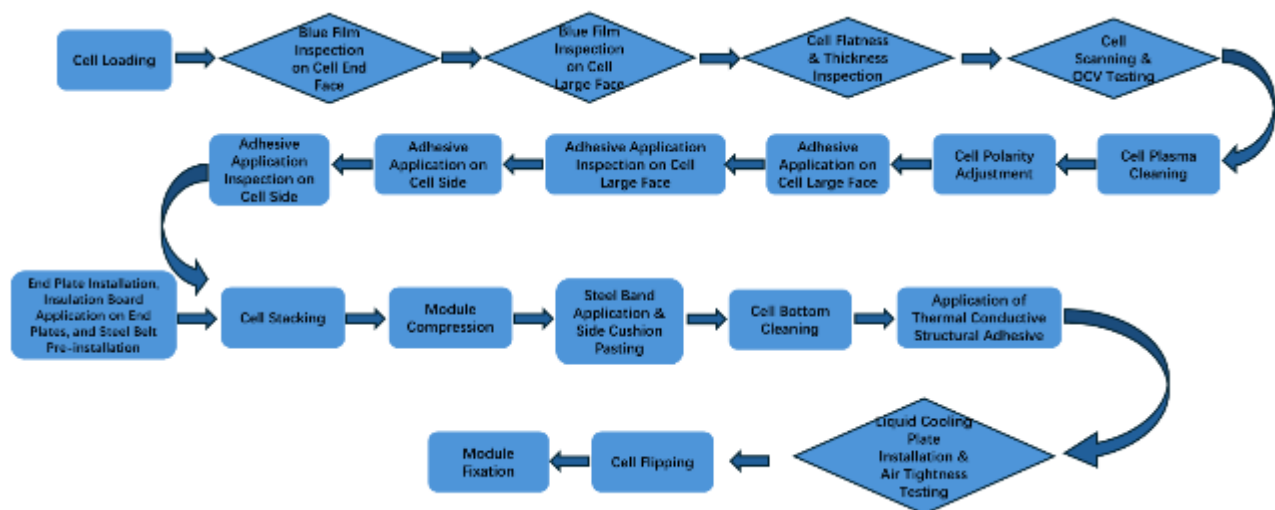


Figure 7-8 Module process flow

The assembly line is equipped with a CCD visual inspection system to photograph and inspect critical processes (see Figure 7-9). If defects are found, the system triggers an alarm, prompting the robot gripper to automatically remove the non-conforming components from the line.



Figure 7-9 Pack assembly area

The cell loading and cleaning procedure commences with an electric forklift positioning the palletized cells into a specified loading station (see Figure 7-10). Subsequently, a robotic arm, equipped with a gripping mechanism, loads and cleans the cells automatically. During the on-site inspection, DNV observed that the robotic arm operating area is enclosed behind a fence, with a laser safety fence installed at the access point, thereby adhering to risk management requirements.



Figure 7-10 Cell loading

During the OCV test and adhesive application step, cells undergo inspection of the blue protective film on the large and end faces after loading. Subsequently, flatness and thickness will be checked, followed by an OCV test, with results automatically recorded, see Figure 7-11. Plasma cleaning and polarity adjustment will then be performed. Finally, adhesive

will be applied to the large face and side, and its quality will be inspected. Quality control and inspection adhere to industrial standards and are highly automated.



Figure 7-11 OCV test and adhesive application

During the cell stacking and module compression step, cells are automatically assembled into a single module. Position detection and mechanical positioning systems are used to ensure precise alignment (see Figure 7-12). The assembled module is then compacted using end plates, followed by compression and securing with a steel band and side cushion. The use of automated stacking reduces the risk of lateral deviation compared to manual stacking and is consistent with best industry practices for automated module assembly.



Figure 7-12 Cell stacking and module extruding

During the cell bottom plasma cleaning and adhesive step, the stacked module undergoes plasma cleaning prior to the application of a thermally conductive structural adhesive (see Figure 7-13). The use of this adhesive supports a reduction in the number of structural components required in the pack's bottom case, while maintaining structural integrity and improving overall pack compactness. This approach is consistent with sound engineering design principles and common industry practices.

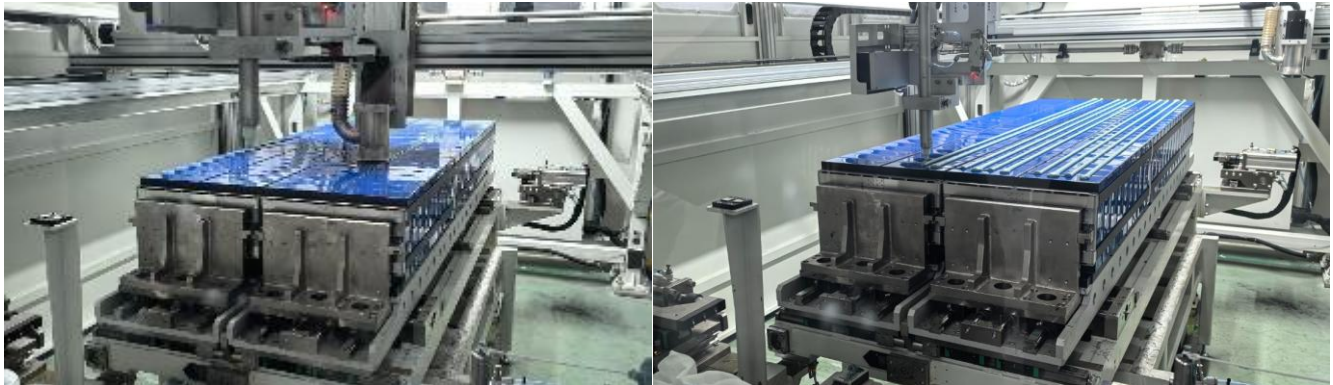


Figure 7-13 Plasma cleaning and adhesive

In the cell flipping and module fixation step, the bottom case is loaded by the AGV. The module, with adhesive applied to its bottom surface, is then flipped and adhered to the bottom case (see Figure 7-14). Each assembled bottom case subsequently undergoes a leakage test to verify seal integrity and confirm the absence of leaks.



Figure 7-14 Module flip, AGV and leakage test

Pack assembly is partially performed manually, including tasks such as CCS and insulation, front cover assembly, and explosion valve assembly. Therefore, strict adherence to the Standard Operating Procedures (SOP) is crucial at this stage, see Figure 7-15.

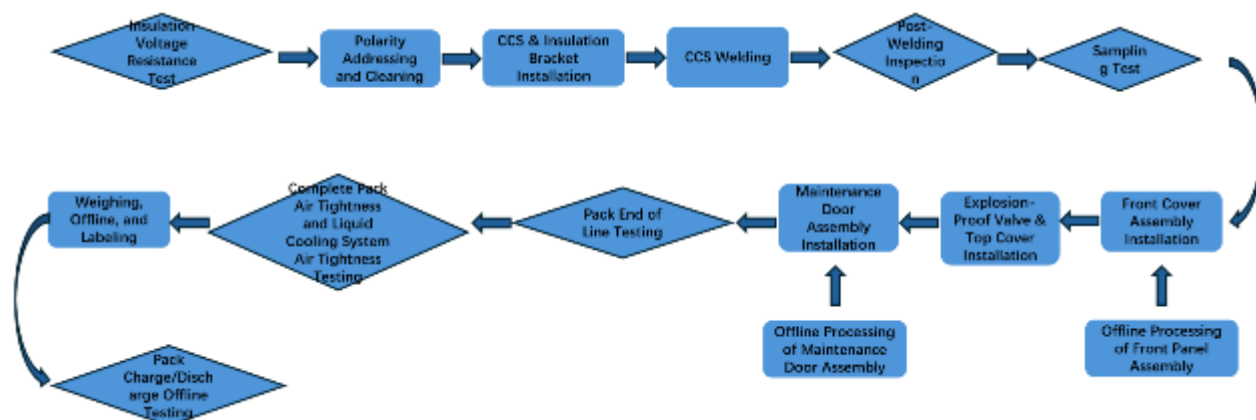


Figure 7-15 Pack process flow

During the polarity addressing step, a CCD camera is used to automatically inspect cell polarity alignment (see Figure 7-16). Cells that do not meet the specified requirements are segregated for further inspection and rework. Following polarity verification, laser cleaning is performed to ensure that the contact surfaces are adequately clean prior to CCS welding. Maintaining a clean surface through laser cleaning is critical to CCS welding quality, as it reduces the risk of welding defects and supports the durability and reliability of the welded connections.

After CCS welding, a post-weld inspection is conducted, as welding quality is critical for the electrical connectivity and subsequent module End-of-Line (EOL) testing. In addition to standard tests, e-STORAGE performs module critical dimension inspections, which provide additional verification beyond baseline industry practices.

For welding and fusion welding processes, a tensile test is performed on one battery cell at the start of each production day. Different welding points are selected each day for first-piece inspection; however, records of the selected points were not previously retained. To address this gap, CSI will implement measures to record the welding points inspected for the first piece on the first-piece inspection form. In addition, the serial number of the top cover is recorded to ensure that different welding points are selected for inspection each day. During ongoing welding operations, weld quality is automatically monitored using a CCD vision inspection system.



Figure 7-16 Welding and inspection

During this process, bolts are tightened using calibrated torque wrenches to ensure proper fastening (see Figure 7-17). During the upper cover installation, a CCD visual inspection system verifies the radius of the screw holes and the gap

between the inner and outer concentric circles. These inspections support accurate alignment, reducing the risk of assembly-related mechanical issues, and help ensure compliance with specified dimensional tolerances.

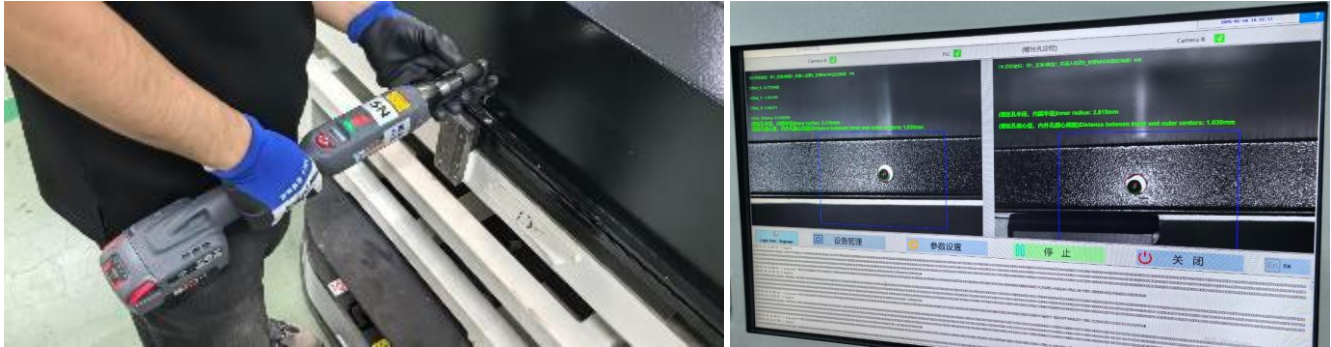


Figure 7-17 Installation and inspection

After installation of the upper cover, an EOL test is conducted (see Figure 7-18). This is followed by a leakage test performed on the bottom case to verify coolant sealing and on the entire pack to assess overall leakage integrity. Units that successfully pass these tests are released as quality-approved units, transferred by an AGV and stored in a designated area pending further system integration. Packs not meeting acceptance criteria (NG packs) are segregated and transferred to the designated NG area for further inspection.

These processes are consistent with common industry practices.



Figure 7-18 EOL and leakage test

The quality-certified pack will be transferred by an AGV and manually stored in a designated area for subsequent processing.

7.2.6.3 ESS Container assembling factory

ESS containers are assembled in-house. Quality-certified battery packs are stored in this area and then lifted into containers for installation using forklifts (see Figure 7-19). This assembly process is predominantly manual and is consistent with common industry practices for containerized ESS.

Key requirements for this operation include ensuring that torque wrenches are properly calibrated at defined intervals, installation personnel are adequately trained and technically certified, and workers are equipped with appropriate PPE. Site engineers are required to perform installation activities in accordance with approved SOPs. In addition, quality control engineers must follow established inspection protocols and maintain appropriate records.



Figure 7-19 CSI ESS container assembly

The container assembly process includes container cleaning, busbar connection, communication line connection, power line connection, liquid cooling pipe connection, and other related tasks, see Figure 7-20. After installation, the system will undergo a leakage test, followed by coolant filling. Subsequently, a Factory Acceptance Test (FAT) will be performed. Systems that pass the quality checks will be packed and stored, awaiting shipment.

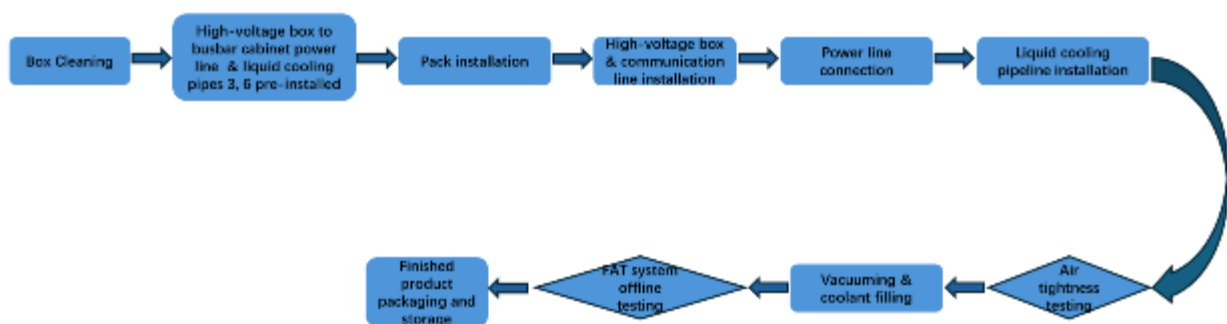


Figure 7-20 SPB 3.0 Process Flow

During on-site inspections, it was confirmed that only trained and authorized personnel, identified with badges and valid work permits, are permitted to perform installation activities (see Figure 7-21). These personnel wear armbands and are distinguished from new employees. All on-site personnel wear observed to be wearing appropriate PPE. In addition, random checks and on-site verifications were conducted to confirm that their torque wrenches were properly calibrated.



Figure 7-21 Work permits, new employee's armbands, PPE and torque wrenches

In addition, SOPs are readily available to on-site personnel. These SOPs provide detailed job descriptions. The Process Flow Card includes key information such as task description, status (OK/NG), date, responsible technicians, and quality control confirmation, providing traceability of production and inspection activities (see Figure 7-22).

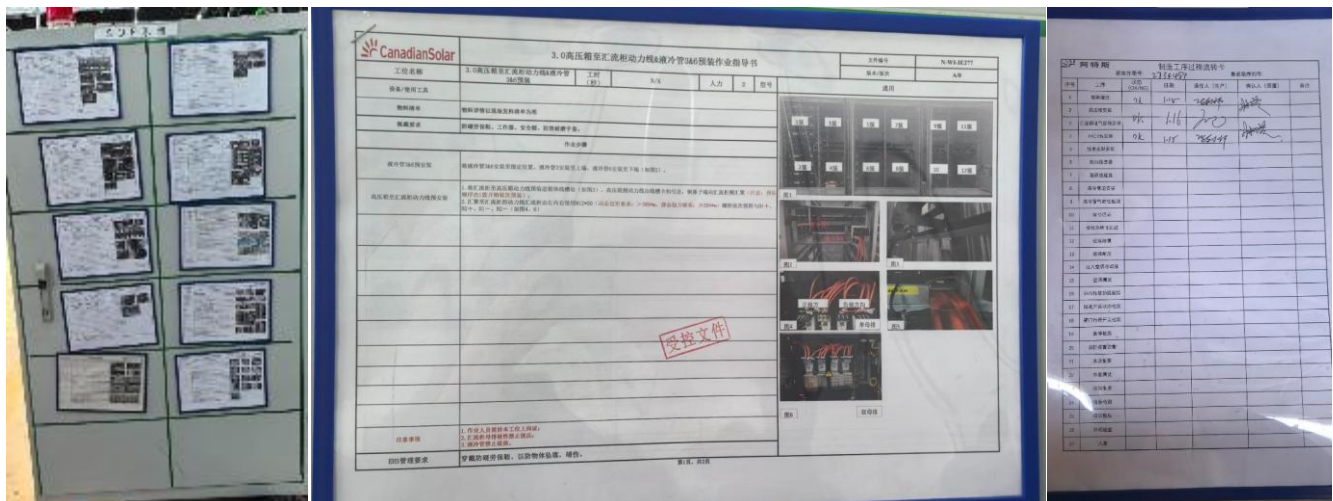


Figure 7-22 SOP, SOP detail and process flow card

During the on-site audit, it was identified that production activities took place in October, while the controlled release date of the relevant SOP was in November. As a result, no formally released guidance documents were available to govern production activities during October and part of November. CSI explained that the SolBank 3.0 was in the trial production phase during this period and operations were conducted using signed and approved temporary documents that had not been released through the OA system. Consequently, the corresponding controlled SOP versions in the OA system had not been updated to reflect the temporary documents in use.

CSI proposed corrective measures requiring that future controlled documents in the OA system be updated based on the corresponding temporary document versions. For products in trial production that are intended for shipment, SOPs are

required to be formally controlled and released in the OA system prior to the start of production, with oversight responsibility assigned to the DQE function.

The Document Control Procedure defines requirements for the management of temporary documents. Temporary documents are issued through the OA system and are subject to full version control. Prior to expiration or transition to mass production, all temporary documents must be formally converted into official OA-controlled versions. Traceability between trial-production documents and their corresponding official versions is maintained through documented version history records within the OA system. Once the official version is approved, the Document Control Center (DCC) is responsible for printing and distributing controlled copies to ensure that only the latest approved documents are available and used at the production site.

CSI's battery module, battery pack, and system production plant in Suzhou is a fully automated facility. A recent DNV audit identified several issues related to EHS document signature confirmation, warehouse temperature and humidity management, supplier evaluation records, FIFO implementation, PFMEA severity definition, IQC area management, test condition control and recording, tool calibration, production records, and SOP document control.

In response to these findings, CSI conducted a thorough root cause analysis and implemented targeted improvement measures. An execution plan was developed, responsible personnel were assigned, and corrective actions were completed, demonstrating quality awareness and continuous improvement capability.

CSI has provided evidence indicating that most issues identified during the DNV audit have been addressed. This includes corrective actions related to EHS document approval, warehouse environmental controls, supplier evaluation records, PFMEA severity interpretation, IQC area compliance, test condition control, tool calibration, and production record accuracy. In addition, CSI submitted system screenshots and written explanations demonstrating how FIFO and document control are managed. However, complete SOP sections explicitly detailing the FIFO procedure were not provided.

Although some documentation remains outstanding, the available evidence indicates that corrective actions have been implemented and that improved controls are functioning effectively in practice. CSI is expected to complete and formally release the remaining SOP documentation to achieve full alignment with internal procedural requirements and audit expectations.

7.3 Battery pack and enclosure quality and manufacturing (Dafeng)

DNV performed a site visit to e-STORAGE's manufacturing facility on 14 March 2025. The manufacturing facility is located at No. 3, Yong Sheng Road, Economic Development Zone, Dafeng District, Yan Cheng, Jiangsu, China. The objective was to confirm that CSI has processes in place to deliver the expected product quality. The site visit focused on two elements:

- Quality control procedures
- Manufacturing process characterization for pack and BESS.

7.3.1 Quality systems evaluation

Canadian Solar's management system is built based on ISO 9001:2015 (quality system), ISO 14001:2015 (Environmental system), and ISO 45001:2015 (occupational health and safety system). DNV verified the list of certifications held by CSI Solar Co., Ltd listed in Table 7-8, which contains information related to the holder, certificate number, and validity dates [126], [127], [128]. The certificate scope covers design, manufacturing and sale of BESS products. At the time of inspection, all quality certificates were valid.

Table 7-8 CSI BESS integration facility (Dafeng, China) quality certifications

Standard	Description	Certificate Organization	Validity
ISO 9001:2015	Quality Management Systems	TÜV Rheinland	05 Aug 2027
ISO 14001:2015	Environmental management systems	TÜV Rheinland	23 Mar 2028
ISO 45001:2018	Occupational Health and Safety Management Systems	TÜV Rheinland	23 Apr 2028

The hierarchical department structure is clearly demonstrated in the company quality organization chart (as shown in Figure 7-23), including an in-house quality department for energy storage business.

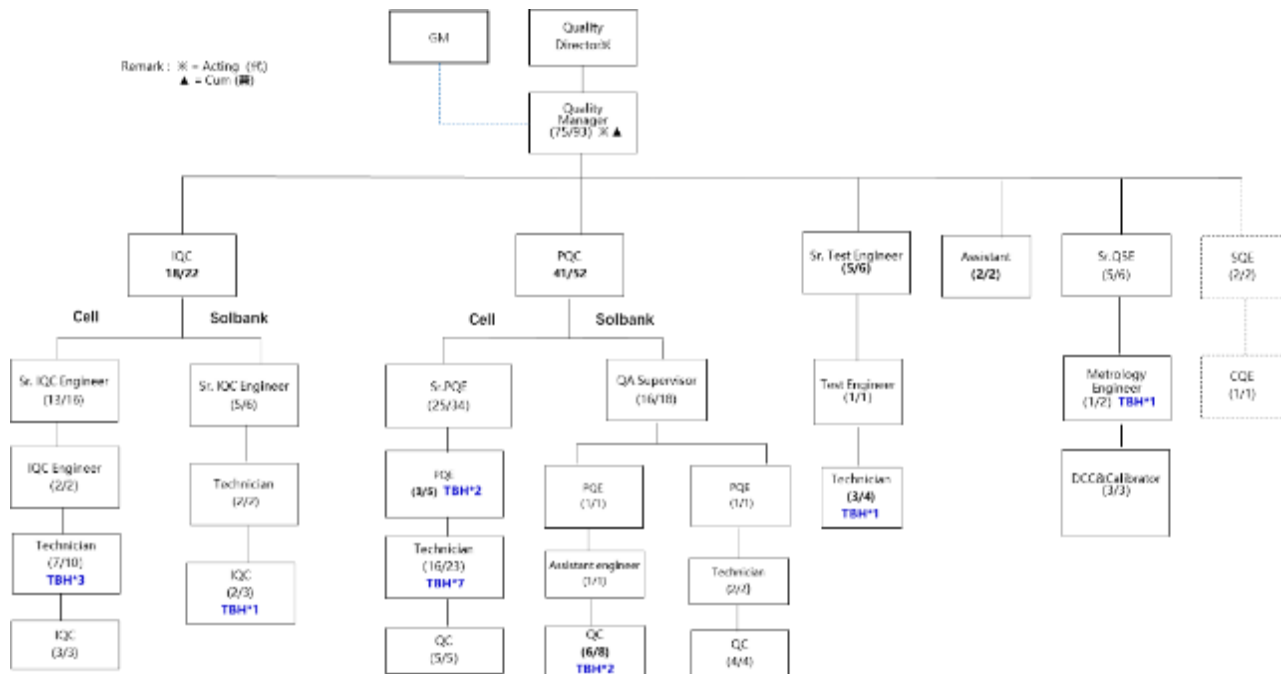


Figure 7-23 Dafeng factory quality organization chart

7.3.2 EHS

During the site inspection for Environmental, Health, and Safety (EHS) hazard identification, CSI (Dafeng) conducted a comprehensive risk assessment [129]. Based on this assessment, CSI (Dafeng) developed a personal protective equipment (PPE) management and Emergency Response Guide (ERG). Additionally, they provided evidence of safety inspections, fire explosion risk assessments, and electrical safety procedures.

They have also completed safety training and possess specialized training to analyze accidents occurring within the same industry. For instance, one accident occurred at a battery company due to equipment maintenance issues, and another fire

accident happened during the battery formation stage. DNV considers it the best practice to learn from competitors' incidents, in addition to their own.

7.3.3 Supplier inspection

Both the Dafeng and Suzhou plants utilize the same supplier management system, thus no further tracing is required in this context. The specific processes can be referenced in Section 1.1 herein. During this factory audit, we conducted a spot check of their actual supplier management practices. It was confirmed that their system adheres to the company's supplier management regulations and maintains detailed records within the system. Shown in Figure 7-24.



合格供应商申请单		CSIF-PD-027 A/0
申请信息		申请单号: HGGY20241115012
申请部门: 采购部/Procurement	申请日期: 2024-11-15	
申请人: 陈亚娟/Yajuan Chen	物料名称: 314Ah锂离子电池	
物料分类: 储能	物料等级: A	
规格描述: 电压/71173314 207.11x71.7x174.7/LFP/314Ah		
料号: 81001663		
供应商: 厦门海辰储能科技股份有限公司	供应商代码: 100478	
地址: 厦门火炬高新区同安园南路1号		
供应商联系人: 陆佳庆	供应商联系人电话: 18862588987	

Figure 7-24 Qualified supplier application form

7.3.4 Warehouse management

The Dafeng plant features a spacious warehouse where key components, such as batteries, are stored in designated areas with controlled temperature and humidity. Material information is recorded and managed using the SAP system, which includes a Warehouse Management (WM) module for managing material storage locations.

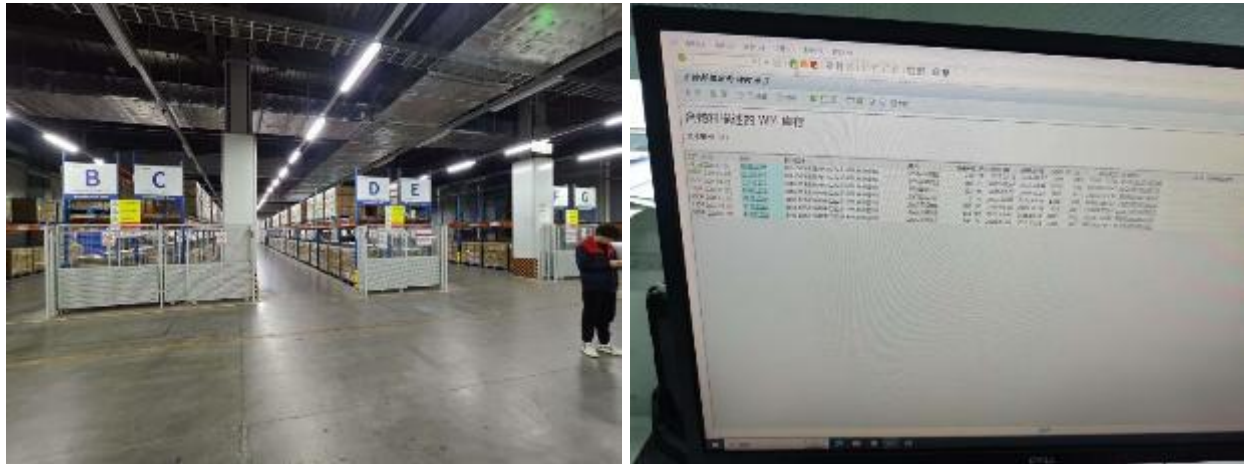


Figure 7-25 Warehouse and SAP system screenshot

DNV conducts random checks on battery pack traceability, and the system is capable of tracing the battery pack back to its position within the warehouse. This integration of SAP system not only facilitates component traceability but also assists the warehouse in ensuring First-In-First-Out (FIFO) inventory management.

The warehouse includes a specific area for Incoming Quality Control (IQC). Materials awaiting inspection are stored in the pending inspection area. After IQC, qualified materials are stored in the warehouse, while non-conforming materials are placed in the non-conforming area for further action. DNV conducts random audits on IQC test reports to verify compliance and accuracy. CSI maintains comprehensive and traceable test records. DNV has confirmed that all testing instruments have valid calibration labels, ensuring proper functioning and accurate measurements. This verification is essential for maintaining the quality and reliability of the testing process.



Figure 7-26 IQC



Figure 7-27 Pending Inspection Area, Qualified Area and Non-Qualified Area

7.3.5 FMEA

CSI implements the latest Process Failure Mode and Effects Analysis (PFMEA). The key parameters include Severity (S), Failure Mode (FM), Failure Cause (FC), Failure Consequence (PC), Detection Control (DC), Detection (D), and Action Priority (AP). This updated version emphasizes the use of the new Action Priority metric, which replaces the traditional Risk Priority Number (RPN). This change enhances the effectiveness and practicality of risk management, thereby ensuring product quality and customer satisfaction.

DNV recognizes CSI's adoption of the latest PFMEA version and its application in practical analysis, indicating a commitment to quality improvement. DNV recommends developing specific action plans or control plans in future for critical areas to ensure the effective implementation and monitoring of control measures identified by PFMEA.

7.3.6 Manufacturing evaluation

DNV's site visit was focused on two elements:

- Overall quality control review
- Production process characterization and production process quality control for module and pack and BESS Container

7.3.6.1 Module and pack assembly

The automatic assembly line for prismatic cell modules includes key processes such as module assembly and pack assembly. CSI module assembly employs automatic assembly and Automated Guided Vehicles (AGVs) for logistics, aligning with industry standards. The detailed module and pack assembly are outlined in Figure 7-28.

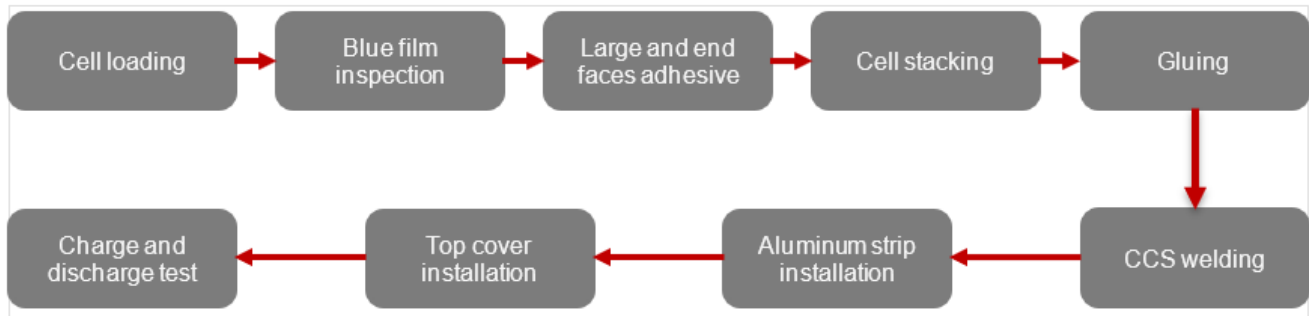


Figure 7-28 Pack process flow

Cell loading and inspection: The process begins with an electric forklift placing palletized cells at a designated loading station. CCD vision equipment automatically inspects the cell surfaces and sides for defects such as pits, broken blue film, and other irregularities. Based on predefined inspection parameters, the system classifies products as acceptable or defective (NG), with NG items automatically flagged and transferred to a rejection area.

A robotic arm with a specialized gripper then handles and cleans the cells. The system monitors grip and placement completion, with built-in computational functions for error detection and alarm triggering.

During on-site inspection, DNV verified that the robotic arm area is secured with protective fencing and a laser safety gate at the entrance, ensuring compliance with risk management standards.



Figure 7-29 Cell loading

Cell stacking and module compression and Steel Band application: The battery cells are automatically assembled into a unified module. Precision alignment is achieved through integrated position detection and mechanical positioning systems. Following assembly, the module undergoes compaction via end plates. The automated stacking process eliminates lateral deviation risks associated with manual stacking, establishing this method as an industry best practice. This approach ensures high precision while maintaining full automation.



Figure 7-30 Cell stacking

Following assembly, the stacked cells undergo compression and are securely fastened using a steel band with protective side cushioning. While this securing method is currently performed manually in common industry practice, the process ensures structural integrity and stability of the assembled module.

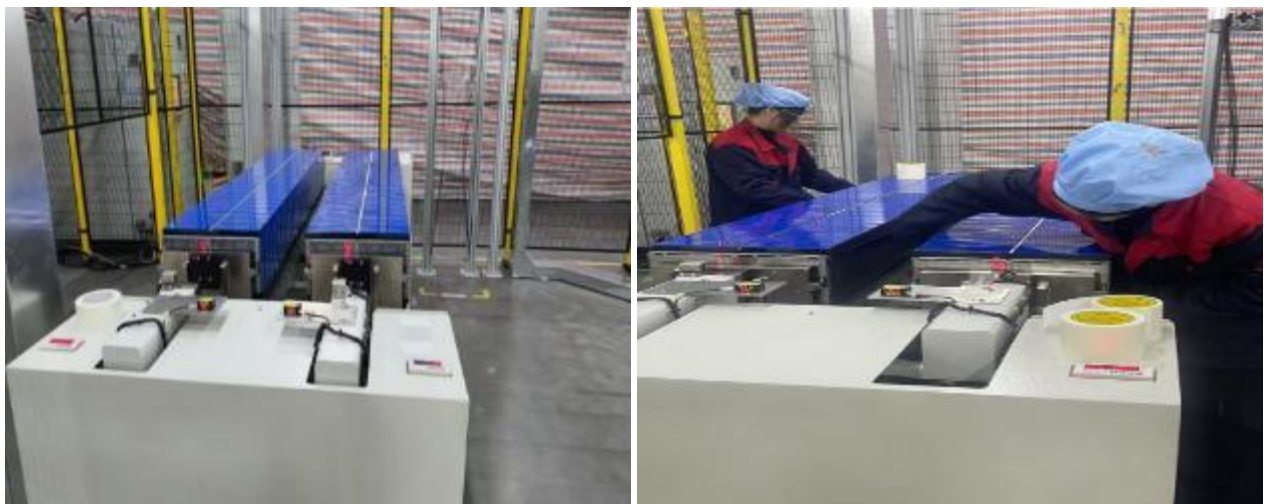


Figure 7-31 Steel Band Application

Cell bottom plasma cleaning and gluing: The stacked module will be subjected to plasma cleaning prior to the application of a thermally conductive structural adhesive. The use of this adhesive has the potential to minimize the structural components of the pack's bottom case, thereby maintaining structural integrity while enhancing the compactness of the pack. This methodology is regarded as good design and practice. The gluing device high-pressure precision metering technology for two-component adhesive mixing, featuring real-time glue pressure monitoring to ensure synchronized filling and discharging of metering cylinders. This process maintains balanced pressure and delivers accurate volumetric control. An integrated

servo-photographic monitoring system verifies gluing quality in real time, ensuring stable adhesive output while maintaining consistent application area and uniform thickness across all products.

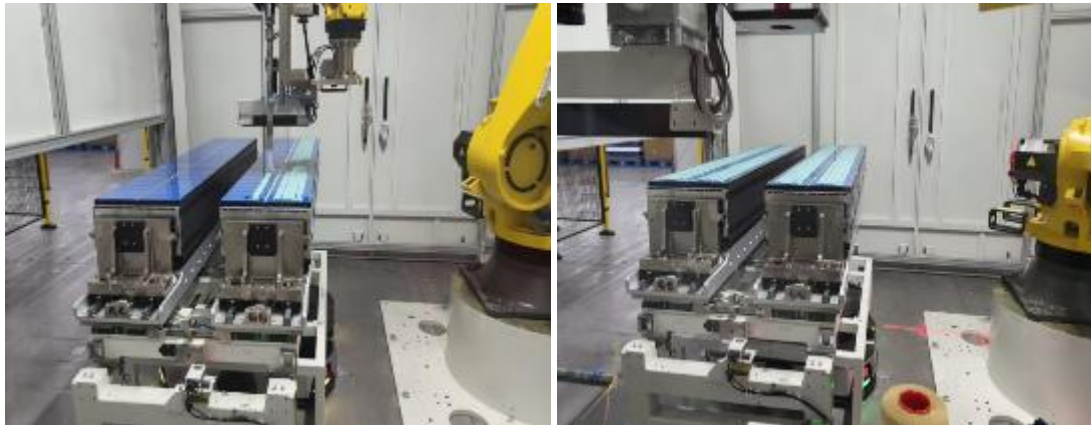


Figure 7-32 Gluing

Cell flipping and module fixation: The bottom case will be loaded by the AGV. The adhesive bottom of the module will be flipped and adhered to the bottom case. Following assembly, each unit is subjected to a comprehensive leakage test to verify seal integrity and ensure product quality before advancing to subsequent production stages.



Figure 7-33 Module flip and AGV

The pack assembly process is partially executed manually, encompassing tasks such as the assembly of the Current Collecting System (CCS), insulation components, front covers, and explosion valves. Consequently, rigorous compliance with the Standard Operating Procedures (SOP) is essential during this phase.

Current Collecting System (CCS) welding: After the CCS is manually positioned on top of the pack, the CCS welding device performs automatic laser welding to establish electrical connections between the poles and connecting pieces, enabling the series and parallel configuration of the battery cells. This stage is highly automated for precision and efficiency.



Figure 7-34 CCS positioning

The welding arm utilizes a ring-spot laser, a welding scanner, and a high-precision vision system equipped with detection and fool-proofing capabilities. This ensures high concentricity between the welding trajectory and the pole, guaranteeing consistent weld quality.

The on-site inspection verifies the first welded piece of the CCS (Current Collecting System) at the start of each shift, conducting inspections and maintaining weld quality records tied to the corresponding inspection serial numbers.



Figure 7-35 CCS welding

Front Cover Installation, Explosion-Proof Valve and Upper Cover Installation: This process is semi-automated, incorporating the assembly of the front cover, explosion-proof valve, and upper cover. The periodic calibration of torque wrenches is essential in this process. On-site random inspection confirms that torque wrenches are properly calibrated and operating within their valid certification period.

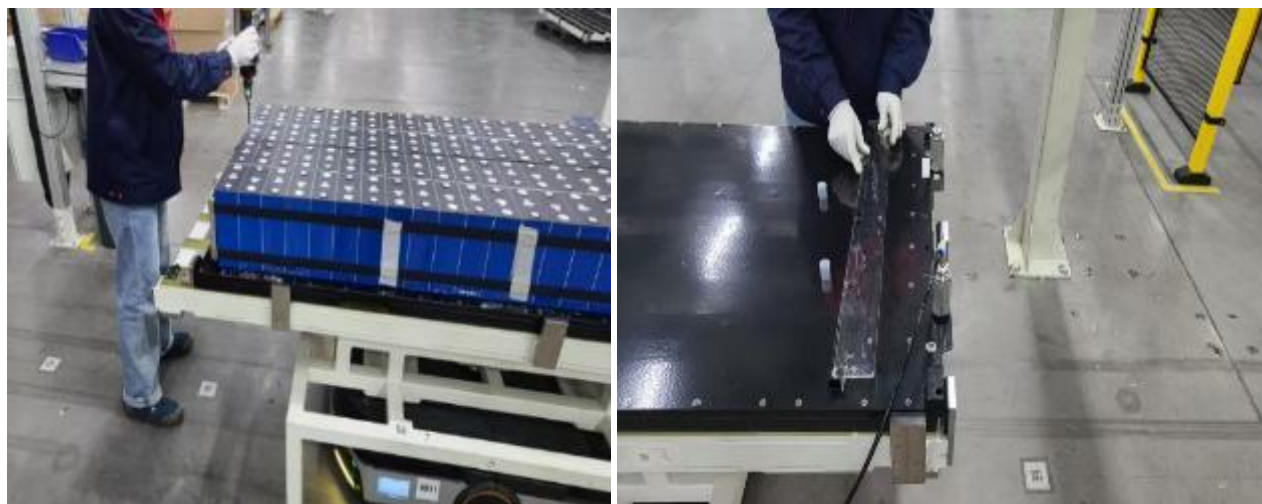


Figure 7-36 Pack installation

EOL, leakage test: Upon completion of upper cover installation, an End-of-Line (EOL) test is conducted, followed by comprehensive leakage testing that includes both coolant system verification (bottom case inspection) and full pack integrity assessment; all quality-approved units are then transferred to a designated staging area for system integration, while any non-conforming (NG) packs are immediately quarantined in a segregated zone for root cause analysis and disposition in accordance with industry standards.



Figure 7-37 EOL and leakage test

The AGV-MES integrated system manages production data collection, performance testing, and equipment control through its central controller, featuring real-time alarm triggering and failure analytics for out-of-spec results, with AGVs transporting passed units to manual staging areas for further processing per quality standards.



Figure 7-38 AGV-MES integrated system

7.3.6.2 ESS Container assembling factory

ESS containers are assembled in-house, where quality-certified battery packs are stored before being lifted into containers for installation using forklifts. This predominantly manual process aligns with industry standards and requires properly calibrated torque wrenches, trained and certified personnel with full PPE, strict adherence to SOPs by site engineers, and compliance with quality check protocols and documentation by QC engineers.



Figure 7-39 CSI ESS container assembly

The container assembly process involves cleaning, busbar installation, communication and power line connections, and liquid cooling pipe integration. After assembly, the system undergoes a leakage test, coolant filling, and a Factory Acceptance Test (FAT). Approved systems are then packed, stored, and prepared for shipment.

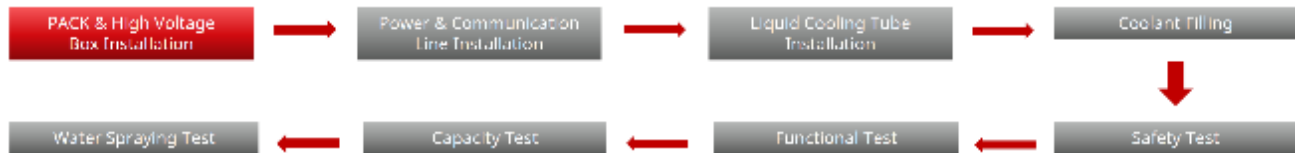


Figure 7-40 SPB 3.0 Process Flow

Pack & high voltage box installation: The PACK is positioned into the battery rack using a stacker truck, ensuring the locating cone aligns with the locating hole. The high-voltage box is then manually pushed into the bracket until its base is level with the bracket's bottom. Installation is performed only by trained, badged personnel with valid work permits—distinguishable from new employees, who wear armbands. All on-site personnel wear full PPE, while random checks verify torque wrench calibration and adherence to safety protocols.



Figure 7-41 Work permits, new employee's armbands, PPE and torque wrenches

Power & Communication Line Installation: The high-voltage connector dust cap is removed before installation. Following the series connection sequence, the appropriate power and communication cables are selected to interconnect the packs within the cluster. These cables are then secured using bundle ties to ensure proper routing and strain relief.



Figure 7-42 Power & Communication Line Installation

Liquid Cooling Tube Installation and Filling: The liquid cooling tubes are installed in sequential left-to-right order, with each connection firmly pressed until audibly secured and then fastened with a bundle tie. An airtightness tester is then connected to the power supply and attached to the top of the liquid cooling tube; the system passes inspection if air leakage remains below 100 Pa.

Next, the 380V power supply is connected to the junction box, and the water-cooled unit's power switch is activated. The liquid injector switch is turned on, followed by enabling the control power and system initialization. Finally, the liquid injection tube is connected to the water-cooled unit to commence coolant filling.



Figure 7-43 Liquid Cooling Tube Installation and Filling

Pre-Delivery Test: Following container integration, the system undergoes mandatory verification testing, including safety tests (such as emergency shutdowns, and insulation), functional tests (control systems, communications), capacity tests (performance validation), and water spray tests (IP protection). All results are documented in the quality system, with non-conformances resolved prior to shipment approval.



Figure 7-44 Pre-Delivery Test

Dafeng Factory's production automation and quality control systems meet or exceed current industry standards. The facility has demonstrated effective root cause analysis and implementation of corrective actions for issues identified during first site inspection, with complete documentation maintained. These practices indicate a well-established quality management system with continuous improvement capabilities.

8 SERVICE INFRASTRUCTURE EVALUATION

8.1 Service organization overview

e-STORAGE makes use of an in-house monitoring/asset management software called CSEye, which provides 24x7 remote monitoring, diagnostics, and troubleshooting capabilities for 365 days of the year [130]. Daily, monthly, and annual reports can be created which provide performance statistics for the relevant operational period being reported on, as well as summaries of preventative maintenance work conducted, use of spare parts, and any root cause analyses for corrective maintenance that may have occurred. e-STORAGE can maintain an inventory of spare parts either on or off-site per the requirements of the respective project owner.

DNV requested information pertaining to the locations of the service centers, the location of the network operation center (NOC), if present, as well as the organizational chart of the O&M services team. e-STORAGE stated that the field service team is setting up a service center in Arizona, and their current NOC is in Guleph, Ontario in Canada. DNV reviewed the organizational chart provided by e-STORAGE [131], and considers it to be within typical expectations for O&M service providers.

e-STORAGE provided DNV with its corrective and preventive action process (CAPA) [132]. It outlines the procedures and responsibilities for identifying, investigating, correcting, and preventing nonconformities within e-STORAGE's business operations, quality management system, processes, products, and services. The purpose of this procedure is to ensure continuous improvement and enhance customer satisfaction by addressing issues systematically. In addition, 8D (Eight Disciplines) is in place for problem-solving process [133], which is a structured approach to identifying, correcting, and preventing issues. This template is used to document the entire process, from problem description to the implementation of corrective actions and lessons learned.

The CAPA process is applicable to all e-STORAGE regions outside China and affects all departments. It involves several key roles, including the quality department, corrective action request (CAR) initiator, CAR assignee(s), and management/leadership. The CAR document outlines the process for managing CARs to ensure problems are resolved and prevented from recurring [134]. Verification of corrective actions is done through review, inspection, testing, or auditing and all evidence is uploaded to the CAR Log. The quality dashboard monitors trends and reports on CAR progress.

Logs events and maintenance activities at the CALD-BESS site from August to November 2024 was provided [135], detailing scheduled and unscheduled events, including alarms and data loss incidents. It tracks issues like inverter failures, communication losses, HVAC repairs, and high battery temperatures, ensuring all are documented, investigated, and resolved.

DNV considers it to be in line with industry expectations.

8.2 Warranty review

DNV was provided with SolBank 3.0 Limited Warranty which is provided as part of the applicable supply or EPC agreement to a project [136]. The Limited Warranty covers any BESS component defects or capacity shortfalls for an initial period of 3 years, extendable for up to 20 years from the Warranty Start Date.

The limited warranty also includes a capacity as well as RTE guarantee, with a limit on the maximum annual as well as daily cycles that the BESS can undergo. If a capacity or RTE Shortfall occurs, e-STORAGE shall owe liquidated damages (LDs) as follows:

- Capacity Shortfall Damages Rate: USD \$0.72 per kWh per month
 - Damages Cap: Greater of: (a) 1% of the original purchase price for the SolBank 3.0 under the Agreement per annum or (b) 100% of Warranty Fee per annum
- RTE Shortfall Damages Rate: USD \$0.024 per kWh of extra charge energy due to the RTE Shortfall
 - Damages Cap: 0.1% of the Purchase Order Amount over a Warranty Year

Defects include component failures that do not perform up to the manufacturer's specifications. e-STORAGE has an obligation to repair or replace any defective components and shall commence investigating and remedying defects within 5 business days after receiving a valid claim. If the defect constitutes a Capacity Defect, the timeline for investigating and remedying the Defect shall be within 48 hours of being notified. If a Defect results in capacity or RTE shortfall, e-STORAGE shall owe liquidated damages. Defects are repaired and replaced even if overall plant performance remains unaffected.

The Limited Warranty provides a clause for Serial Defects, when a Defect is identified in at least 30% of SolBank 3.0s in the BESS, or any component within, and the cause of such Defect is substantially the same or similar. DNV notes that this value is higher than typically expected for Serial Defect percentages, and that the typical range is around 5-10%.

The liability under the warranty is limited to the contract price of the agreement for the initial warranty term. If the warranty is extended, the total liability shall not exceed the contract price multiplied by the applicable SOH guarantee for the respective warranty year. Failure to replace defective components leading to substantial downtime and subsequent capacity/RTE shortfall would be reflected in these metrics therefore triggering appropriate liquidated damages.

DNV finds these terms to be consistent with industry standards.

The Limited Warranty includes operating limits that the BESS must adhere to:

- The BESS shall be operated in the range of 0% to 100% SOC.
- The annual average SOC (ASOC) shall be lower than or equal to the maximum annual average SOC (MaxASOC) when auxiliary power is present ($ASOC \leq MaxASOC$).
- During operation, the ambient temperature shall be in the range -30 °C and 55 °C.
- During storage, the BESS SOC shall remain between 30% and 40%.
- During storage, the BESS shall remain within an ambient temperature range of -30 °C and 45 °C, with further restrictions on a cumulative period of 736 hours during which the temperature exceeds 35 °C, and a cumulative period of 736 hours during which ambient temperature drops below -20 °C.

Defects resulting from the use or operation of the BESS beyond, or in contravention of, the operating limits are excluded from the Limited Warranty.

DNV considers the terms of the limited warranty to be in line with typical industry expectations.

8.2.1 Capacity maintenance/performance guarantee

The SolBank 3.0 Limited Warranty states a capacity guarantee, which guarantees that the storage capacity of SolBank 3.0 during the Warranty Period will be equal to or greater than the applicable Guaranteed Energy Capacity (GEC). If the GEC is not satisfied, capacity shortfall damages are owed as stated above in Section 8.2 herein.

In order to demonstrate that e-STORAGE has not satisfied the capacity guarantee stated above and claim a capacity shortfall, it is mandatory to conduct a storage capacity test, and the GEC shall be calculated by initial storage capacity (ISC) times the guaranteed SOH:

$$GEC_n = ISC_{kWh} \times SoH_n$$

Where:

GEC_n is the applicable Guaranteed Energy Capacity of Warranty Year n.
 ISC_{kWh} is the Initial Storage Capacity in kWh per Section 1 of this Exhibit A.
 SoH_n is the Guaranteed State of Health.

It is noted that the measurable capacity during periods when BESS power is at or above 95% of the target power level will be limited to approximately 97% to 99% of SolBank 3.0's GEC. The unreleased capacity is expected to be fully accessible during the charge top-off period and discharge tail-end period of the cycle. DNV considers this to be reasonable and in line with typical BESS operation.

DNV reviewed the base SOH of SolBank 3.0 provided in the Limited Warranty. The table below indicates that for both 2-hour and 4-hour systems, at 365 cycles per year (one cycle per day), the BESS SOH is expected to remain above 60% after 20 years of operation, which aligns with DNV's expectations for BESS project life. The Limited Warranty also provides RTE guarantees, which DNV reviewed and considers to be within expectations.

Table 8-1 Guaranteed RTE and SOH

Warranty Year	0.25P SolBank 3.0 (365 cycles per year)		0.5P SolBank 3.0 (365 cycles per year)		0.5P SolBank 3.0 (730 cycles per year)	
	Applicable SOH	Guaranteed RTE	Applicable SOH	Guaranteed RTE	Applicable SOH	Guaranteed RTE
1	96.09%	93.90%	95.31%	92.80%	93.23%	92.80%
2	93.03%	93.85%	92.63%	92.63%	88.77%	92.33%
3	90.13%	93.60%	89.73%	92.41%	85.26%	92.07%
4	88.14%	93.43%	87.69%	92.25%	81.63%	91.79%
5	86.58%	93.30%	86.29%	92.14%	79.07%	91.59%
6	85.59%	93.21%	85.29%	92.07%	77.16%	91.45%
7	84.22%	93.09%	83.96%	91.97%	74.91%	91.28%
8	82.44%	92.94%	82.10%	91.83%	72.93%	91.13%
9	81.03%	92.82%	80.65%	91.71%	71.04%	90.98%
10	79.71%	92.70%	79.19%	91.60%	69.20%	90.84%
11	78.46%	92.60%	77.73%	91.49%	67.43%	90.71%
12	77.47%	92.51%	76.29%	91.38%	65.74%	90.58%
13	76.49%	92.43%	74.83%	91.27%	64.10%	90.45%
14	75.56%	92.35%	73.39%	91.16%	62.55%	90.34%
15	74.66%	92.27%	71.94%	91.05%	61.07%	90.22%
16	73.75%	92.19%	70.49%	90.94%	60.00%	90.14%
17	72.92%	92.12%	69.05%	90.83%	-	-
18	72.09%	92.05%	67.61%	90.72%	-	-
19	71.24%	91.97%	66.17%	90.61%	-	-
20	70.46%	91.91%	64.72%	90.50%	-	-
21	66.09%	91.53%	62.77%	90.35%	-	-
22	64.10%	91.36%	61.50%	90.26%	-	-
23	62.08%	91.18%	60.00%	90.14%	-	-
24	60.00%	91.00%	-	-	-	-

- Note: Values beyond Year 20 are not guaranteed values and are presented in grey.

8.2.2 Long term services agreement (LTSA)

DNV reviewed documents provided by e-STORAGE that provide information pertaining to the O&M service offerings and capabilities [137] [138] [139]. e-STORAGE provides full scope Long-Term Service Agreements (LTSAs) that cover all aspects of O&M services, including but not limited to coverage against defects, preventative and corrective maintenance, periodic monitoring and reporting, and maintaining performance guarantees for availability, capacity, and RTE, among others, see Figure 8-1. LTSAs are available for a fixed fee, excluding Augmentation Fees, for terms of up to 20 years from the date of Substantial Completion. For projects that require Capacity Maintenance, augmentations are included in the LTSAs. The fees for these augmentations are initially provided as estimates and typically finalized before the augmentation events.

DNV requested a sample or reference LTSA from a past project that includes terms and provisions related to the scope of work, warranties, response times, performance guarantees, termination/voiding conditions, and maintenance program details for a high-level review. e-STORAGE informed DNV that each LTSA is unique to the specific project and that further performance guarantees are subject to negotiation. Due to the confidential nature of these agreements, e-STORAGE cannot share project-specific LTSAs.



Figure 8-1 An overview of e-STORAGE's LTSA services

9 ASSESSMENT OF FIELDDED PRODUCTS

DNV received documentation on fleet statistics including the status of the systems (deployed vs operational vs pre/under construction), count and type of systems installed, and the date and location of installations [140] [141]. e-STORAGE currently has 12.461 GWh DC of nominal capacity deployed and operational, 22.973 GWh DC of nominal capacity under construction (contracted/post-NTP), and 0.045 GWh DC of nominal capacity in the pre-construction (contracted/pre-NTP) stage. This represents a total contracted and deployed pipeline of 35.479 GWh DC of nominal capacity. A consolidated summary of the full project portfolio is provided in Table 9-1 below.

Table 9-1 e-STORAGE project pipeline summary

Project Code	MW AC	MWh	MWh DC	COD	Location	Contract	BESS
Deployed and Operational							
USA Project 1	140	560	762	Nov-21	California, USA	BESS	–
USA Project 2	75	300	406	Aug-22	California, USA	BESS	–
USA Project 3	200	800	958	Aug-22	California, USA	Turnkey	–
USA Project 4	150	600	717	Aug-22	California, USA	Turnkey	–
USA Project 5	21	82	106	Oct-22	California, USA	BESS	–
USA Project 6	150	300	392	Aug-24	Texas, USA	BESS	SolBank 1.0
USA Project 7	100	400	516	Aug-24	California, USA	BESS	SolBank 1.0
USA Project 8	100	145	178	Sep-24	Texas, USA	BESS	SolBank 1.0
USA Project 9	120	174	214	Aug-24	Texas, USA	BESS	SolBank 1.0
USA Project 10	206	299	356	Dec-24	Texas, USA	BESS	SolBank 1.0
UK Project 1	26	26	31	Dec-22	Leicestershire, UK	Turnkey	–
UK Project 2	24	24	28	Dec-22	Swansea, UK	Turnkey	–
UK Project 3	22	22	25	Dec-22	Port Talbot, UK	Turnkey	–
UK Project 4	18	18	22	Dec-22	Tyne & Weir, UK	Turnkey	–
UK Project 5	22	44	53	Aug-24	Rhondda, Wales, UK	BESS	SolBank 1.0
UK Project 6	50	99	122	Nov-24	South Gloucestershire, UK	Turnkey	SolBank 1.0
UK Project 7	10	20	24	Aug-24	Forfar, Scotland, UK	BESS	SolBank 1.0
UK Project 8	10	20	24	Dec-24	Braco, Scotland, UK	BESS	SolBank 1.0
UK Project 9	42	84	113	Jan-25	Manchester, UK	BESS	SolBank 1.0
China Project 1	100	200	200	Apr-23	Gansu, China	BESS	SolBank 1.0
China Project 2	50	100	100	Apr-23	Gansu, China	BESS	SolBank 1.0
China Project 3	15	30	30	Dec-23	China	BESS	SolBank 1.0
China Project 4	20	40	40	Nov-23	China	BESS	SolBank 1.0
China Project 5	1	2	2	Nov-23	China	BESS	SolBank 1.0
China Project 6	30	60	60	Dec-23	China	BESS	SolBank 1.0
China Project 7	30	60	60	Jun-24	China	BESS	SolBank 1.0
China Project 8	200	800	800	Dec-24	China	BESS	SolBank 1.0
China Project 9	223	445	445	Jun-24	China	BESS	SolBank 1.0
China Project 10	9	27	27	May-24	China	BESS	SolBank 1.0
China Project 11	4	7	7	Mar-25	China	BESS	SolBank 1.0
China Project 12	9	27	27	Jan-25	China	BESS	SolBank 1.0
China Project 13	18	71	71	Aug-24	China	BESS	SolBank 1.0
China Project 14	2.25	9	9	Jun-24	China	BESS	SolBank 1.0
Total	2,197	5,895	6,924				
Under Construction (Contracted / Post-NTP)							
Canada Project 101	50	200	249	May-25	Nova Scotia, Canada	Turnkey	SolBank 1.0
Canada Project 102	50	200	249	Apr-25	Nova Scotia, Canada	Turnkey	SolBank 1.0
Canada Project 103	50	200	249	Oct-25	Nova Scotia, Canada	Turnkey	SolBank 1.0
USA Project 101	100	400	602	Feb-27	Arizona, USA	BESS	SolBank 3.0

Project Code	MW AC	MWh	MWh DC	COD	Location	Contract	BESS
USA Project 102	98.35	196.7	231	Mar-26	Texas, USA	BESS	SolBank 3.0
USA Project 103	121	242	286	Apr-26	Texas, USA	BESS	SolBank 3.0
USA Project 104	6	24	30	Jan-26	Indiana, USA	BESS	SolBank 3.0
USA Project 105	200	800	1,043	Apr-26	Texas, USA	BESS	SolBank 3.0
USA Project 106	100	200	261	Feb-26	Texas, USA	BESS	SolBank 3.0
USA Project 107	75	150	201	Mar-25	Texas, USA	BESS	SolBank 3.0
USA Project 108	50	100	135	Aug-25	Texas, USA	BESS	SolBank 3.0
USA Project 109	150	600	808	May-26	Arizona, USA	BESS	SolBank 3.0
USA Project 110	200	400	532	Dec-25	Texas, USA	BESS	SolBank 3.0
USA Project 111	160	640	843	Aug-26	California, USA	BESS	SolBank 3.0
USA Project 112	200	800	1,068	Apr-25	Arizona, USA	BESS	SolBank 1.0
USA Project 113	300	1,200	1,519	Mar-25	Arizona, USA	BESS	SolBank 1.0
USA Project 114	100	200	261	Apr-25	Texas, USA	BESS	SolBank 1.0
USA Project 115	304	441	543	Feb-25	Texas, USA	BESS	SolBank 1.0
USA Project 116	2	4	6	Jul-25	California, USA	BESS	SolBank 1.0
Chile Project 101	98	294	361	Dec-25	Pozo Almonte, Chile	Turnkey	SolBank 3.0
Chile Project 102	228	912	1,008	Jul-26	Chañaral, Chile	BESS	SolBank 3.0
UK Project 101	500	1,000	1,261	Dec-25	Scotland, UK	BESS	SolBank 1.0
UK Project 102	500	1,000	1,154	Oct-27	Scotland, UK	BESS	SolBank 3.0
UK Project 103	500	1,000	1,154	Dec-27	Scotland, UK	BESS	SolBank 3.0
UK Project 104	25	50	59	Feb-26	East Lincolnshire, UK	Turnkey	SolBank 3.0
UK Project 105	12	48	59	Jan-26	Sandbach, UK	BESS	SolBank 1.0
UK Project 106	11	22	27	Jun-25	Stanford-le-Hope, UK	BESS	SolBank 1.0
UK Project 107	50	100	122	Feb-25	Cathkin, Scotland, UK	Turnkey	SolBank 1.0
UK Project 108	50	100	122	Mar-25	Broxburn, Scotland, UK	Turnkey	SolBank 1.0
UK Project 109	40	90	107	Jan-26	Stoke, UK	BESS	SolBank 1.0
UK Project 110	30	70	80	Apr-25	Preston, UK	BESS	SolBank 1.0
Australia Project 101	100	200	241	Aug-26	Victoria, Australia	Turnkey	SolBank 3.0
Australia Project 102	100	200	237	May-25	South Australia,	Turnkey	SolBank 1.0
Australia Project 103	240	960	1,114	Nov-26	South Australia,	Turnkey	SolBank 3.0
Japan Project 101	2	6	9	Oct-25	Hokkaido, Japan	BESS	SolBank 1.0
Taiwan Project 101	42	107.1	131	Jun-25	Taiwan	BESS	SolBank 1.0
Taiwan Project 102	21.5	60	71	Jul-25	Taiwan	BESS	SolBank 1.0
Taiwan Project 103	58	149.9	178	Jun-25	Taiwan	BESS	SolBank 1.0
Taiwan Project 104	28.5	78.38	95	Jul-25	Taiwan	BESS	SolBank 1.0
China Project 101	50	50	100	Mar-25	China	BESS	SolBank 1.0
China Project 102	20	40	40	Mar-25	China	BESS	SolBank 1.0
Total	5,022	13,535	16,846				
Pre-Construction (Contracted / Pre-NTP)							
Canada Project	390	1,560	1,941	Apr-27	Canada	BESS	SolBank 3.0
Spain Project 1001	10	40	45	Mar-26	Spain	BESS	SolBank 3.1
Total	400	1,600	1,986				

DNV typically expects BESS availability to be 97% or better for well-performing systems. DNV reviewed availability data for a sample of SolBank 1.0 products provided by e-STORAGE [142]. The results are summarized in Table 9-2. The data indicates that the average availability of the BESS projects presented in Table 9-2 exceeds 98% across all projects, with the exception of Texas Projects 1 and 2. DNV further notes that the observed monthly reductions in availability have been rectified and approach expected performance levels in the most recent month of available data available, which is viewed favorably. DNV expects e-STORAGE to rectify any issues that may arise within the systems to ensure that the systems meet expected availability metrics on an ongoing basis.

Table 9-2 Availability data for select operational BESS

Month-Year	California Project 6	Texas Project 1	Texas Project 2	Texas Project 3	UK Project 5	UK Project 7	UK Project 6	UK Project 8
Jul-24	98.85%	94.6%						
Aug-24	98.3%	97.0%			99.6%			
Sep-24	99.0%	93.3%			96.7%			
Oct-24	99.5%	93.9%	94.8%		99.4%	99.6%		
Nov-24	98.1%	93.0%	87.7%	97.0%	99.1%	98.4%		
Dec-24	99.5%	97.0%	95.2%	99.6%	99.9%	99.4%	99.30%	
Jan-25	99.8%	98.2%	96.9%	99.3%	99.8%	99.4%	97.60%	99.9%
Total average	99.0%	95.3%	93.7%	98.6%	99.1%	99.2%	98.50%	99.9%

DNV also reviewed plant, BESS enclosure, and inverter availability data provided by e-STORAGE [143]. Plant availability considers monthly average availability for site (inclusive of BESS enclosures and inverters), and is then averaged for all sites in e-STORAGE's global fleet on a monthly basis. BESS enclosure availability is weighted based on the number of strings online vs. total number of strings, and this data is taken as a monthly average on a per site basis, and then averaged as a total fleet. Inverter availability is taken as a monthly average on a per site basis, and then averaged as a total fleet. DNV considers it to be in line with industry expectations.

The SolBank operating fleet is expected to rapidly grow in 2026, and its associated availability is expected to continue trending upwards as existing projects accumulate operating time, which DNV views favorably. As the number of installations and enclosures in the operating fleets increase, issues and faults within newly installed systems are expected to arise in the initial stages. DNV highlights the need for regular preventative and corrective O&M to minimize downtime and subsequent unavailability. DNV also recommends routinely following up with sites with any issues, to ensure they are addressed in a timely manner, and the project operates as intended for maximizing output and satisfying any performance guarantees.

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APPENDIX A – HITHIUM

DNV leveraged a prior technology review report of Hithium's 314 Ah cell for this section [144].

A.1 Company Evaluation

Hithium, an energy storage technology company founded in 2019, employs over 8,000 people globally. With a total investment of 4.58 billion USD, Hithium operates three facilities located in Xiamen, Chongqing, and Shenzhen.

- Xiamen facilities: These serve as the company's headquarters and research and development center, employing over 1,000 personnel. The focus here is on advanced battery materials and the recycling of lithium iron phosphate (LFP). The R&D center is accredited by the China National Accreditation Service for Conformity Assessment (CNAS) in accordance with ISO 17025:2017.
- Chongqing facilities: These facilities are dedicated to the production of all Hithium products, ranging from cells to energy storage systems (ESS).
- Shenzhen facilities: This location is focused on research and development of BMS and serves as an innovation center.

Hithium has demonstrated its expertise in providing energy storage solutions across various scenarios and locations in China. However, DNV has not visited any of the project sites and therefore cannot verify the operation and performance of the products in these projects.

The Xiamen factory has 11 production lines; 8 of which produce 314 Ah cells with a total capacity of 32 GWh, and the remaining 3 production lines produce 280 Ah cells with a total capacity of 7.5 GWh. The Chongqing factory has 6 production lines all producing 314 Ah cells with a total capacity of 32.4 GWh.

Additionally, in December 2023, Hithium successfully launched the first phase of 28 GWh in new production capacity at its Chongqing facility in China, shown in Figure A 1. Hithium invested 1.8 billion USD to build this facility, which occupies an 800,000 m² site in the Tongliang high-tech zone. The new capacity, aiming to meet the global demand for 700 GW of energy storage by 2030, will play a significant role in the worldwide energy industry.



Figure A 1 Facility in Chongqing (new production plant)

Hithium has developed a wide range of energy storage products. For battery cells, Hithium offers 50 Ah cylindrical cells for residential energy storage systems (ESS) and portable energy storage. For energy storage cabinets and containers, it offers 280 Ah prismatic cells, 300 Ah prismatic cells, and 314 Ah prismatic cells. In addition, Hithium offers liquid-cooled energy storage system solutions, which includes liquid-cooled battery modules, energy storage cabinets, and containerized energy storage systems.

A.1.1 Intellectual Property

As of November 2023, Hithium has secured over 1,300 patents. Among these, a list of 100 patents related to battery cells was provided, all of which are filed in China. Additionally, Hithium holds 4 patents in the US, 4 in Germany, and 7 in other European countries. DNV has not conducted a detailed review of these patents.

A.1.2 Financial Status

As of 2023, Hithium's sales revenues were as follows: \$5.74 million USD (41.21 million CNY) in 2021, \$506.8 million USD (3,620 million CNY) in 2022, and \$1,416.94 million USD (10,121 million CNY) in 2023. This represents a compound annual growth rate (CAGR) of 527%. Hithium's revenue trend over the past few years is shown in Figure A 2.

The significant revenue growth in 2022 was driven by increased sales of 280 Ah cells and the ESS system, along with the introduction of a 50 Ah cell and battery module. In 2023, Hithium continued to expand its ESS product range and began selling 314 Ah cells, although these accounted for a smaller portion of the overall ESS product sales.

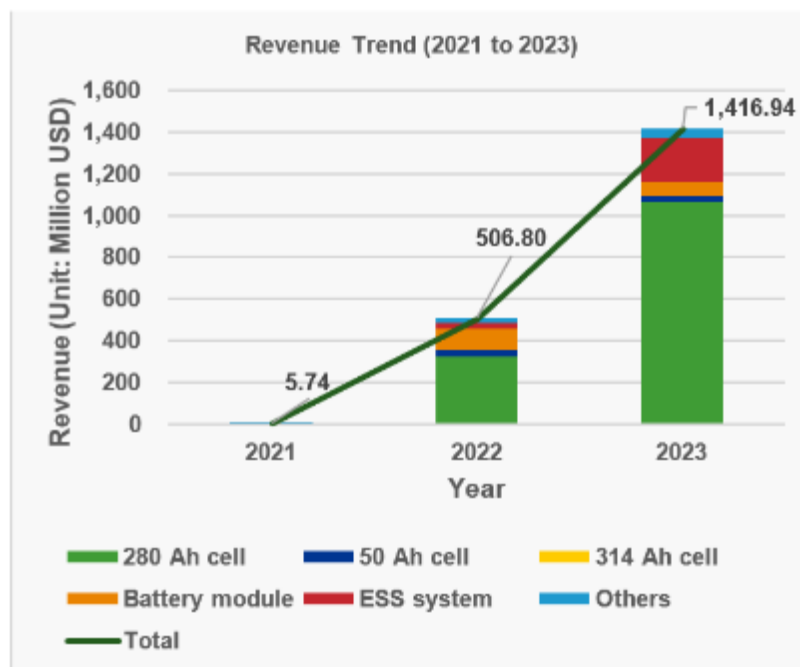


Figure A 2 Sales revenue trend (2021 to 2023)

A.2 Battery cell specifications

Hithium's 314 Ah cell specifications are presented in Table A-1, which includes several parameters such as capacity, operating voltage and operating temperature conditions [145]. Figure A 3 presents prismatic Hithium's 314 Ah LFP cell.



Figure A 3 Hithium's 314 Ah LFP cell

Table A-1 Hithium 314 battery cell specifications

Parameter	Specification
Cell type / chemistry	Type: Prismatic Chemistry: LFP
Cell model	LFP71173207/314Ah
Nominal capacity	314 Ah
Operating voltage range	2.5 V to 3.65 V ($T > 0\text{ }^{\circ}\text{C}$) 2.0 V to 3.65 V ($T \leq 0\text{ }^{\circ}\text{C}$)
Nominal voltage	3.2 V
Nominal energy	1004.8 Wh
AC-impedance	$0.20 \pm 0.05 \text{ m}\Omega$, 27%SOC
Maximum charge/discharge current	314 A
Discharge end voltage	2.5 V
Maximum operating temperature range (Charge)	$0\text{ }^{\circ}\text{C}$ to $60\text{ }^{\circ}\text{C}$
Maximum operating temperature range (Discharge)	$-30\text{ }^{\circ}\text{C}$ to $60\text{ }^{\circ}\text{C}$
Optimal operating temperature range (Charge)	$25\text{ }^{\circ}\text{C}$
Optimal operating temperature range (Discharge)	$25\text{ }^{\circ}\text{C}$
Storage temperature (6 months)	$-20\text{ }^{\circ}\text{C}$ to $35\text{ }^{\circ}\text{C}$

Parameter	Specification
Cell dimensions (W x L x H)	71.70±0.5mm × 174.70±0.5mm × 207.11±0.5mm
Weight	5.60 ± 0.20 kg
Energy density	≥ 175Wh/kg

DNV notes that the charge temperature's lower limit is set above 0 °C, ensuring that the cells are not charged in freezing conditions. The upper limit, on the other hand, is higher than most, typically not exceeding 55 °C. Overall, DNV considers Hithium cell specifications to be in line with similar products in industry.

DNV requested clarification regarding the storage temperature window (-20 °C to 35 °C) of the Hithium cell, which is narrower than the BESS system's specified storage range of -20 °C to 45 °C and recommends updating it once the information is available.

A.3 Performance evaluation

DNV notes that the following performance data is based on tests performed on Hithium 314 Ah LFP cell, which is utilized in SolBank 3.0.

A.3.1 Capacity

Capacity performance testing is essential for assessing the efficiency and reliability of battery cells. This type of testing involves measuring the charge and discharge cycles under controlled conditions to determine the battery's capacity, and voltage behavior. The results highlight a discharge capacity of around 325.3 Ah, which exceeds the target of 314 Ah, and a discharge energy of 1038.6 Wh, surpassing the benchmark of 1004.8 Wh. This indicates efficient performance under the 0.5P test conditions [146].

The test conditions outlined involve charging and discharging a battery at 25 °C with a voltage range of 2.5 V to 3.65 V (100% DOD) at 0.5P rate, see Figure A 4. The graphs display the voltage against capacity and energy for these cycles. The charging curve shows a steady increase in voltage until it sharply rises at the end of the charging process, while the discharging curve indicates a gradual decline in voltage. The data matches expectations.

DNV requested RTE data of Hithium cell and recommends updating it once the information is available..

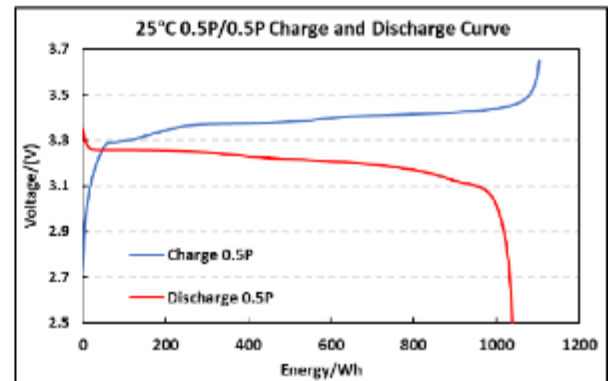
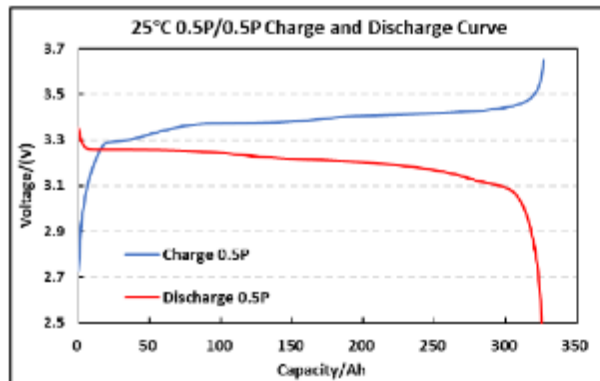


Figure A 4 Charge- Discharge profile at 25 °C, 100% DOD and 0.5 P rate

A.3.2 Power capability and duration

Rate capability in batteries refers to their ability to charge and discharge at different rates without significant performance loss. Temperature significantly impacts this, as higher temperatures typically enhance power capabilities by lowering internal resistance. The charge and discharge curves of the 314 Ah Hithium cell indicate that increase in cycling rates result in slightly lower capacity and energy or as indicated in the document as capacity/energy retention [147]. The discharge performance at 0.5 P versus temperature highlights that while the battery performs optimally at higher temperatures (25 °C to 55 °C), its efficiency declines in colder environments (below zero), which is as expected.

The rate performance test on the 314 Ah cell was conducted at 25 °C, involving charging and discharging cycles at various rates (0.25P, 0.33P, 0.5P, and 1P), see Figure A 5 and Table A-2. The test procedure included charging to 3.65 V, resting for 30 minutes, discharging to 2.5 V, and repeating the process with different rates. Table A-2 which lists capacity and energy retention in percentage. DNV assumes that the data showcases rate capability and capacity/energy at various rates versus capacity/energy at 0.5P rate with the capacity and energy retention marked as 100% at 0.5P. The capacity retention increases from 98.84% to 100.64% during charging and from 98.78% to 100.89% during discharging as the rate decreases from 1P to 0.25P. A similar behavior can be seen with energy retention, which increases from 97.26% to 100.23% as the rate from 1P to 0.25P. DNV notes that e-STORAGE's SolBank 3.0 is only operated up to 0.5P.

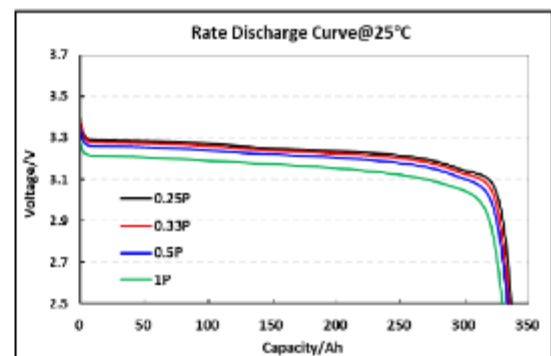
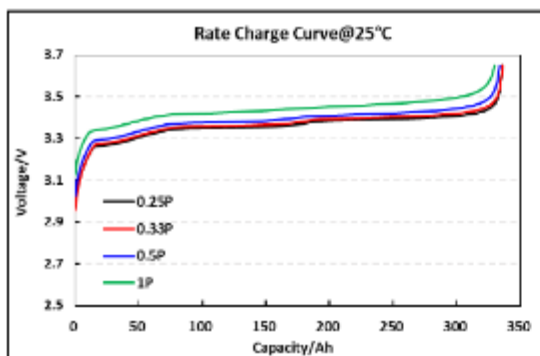


Figure A 5 Charge/discharge performance at 25 °C at different P-rates

Table A-2 Charge/discharge performance at 25 °C at different P-rates

Condition	P-rate	Capacity retention (%)	Energy retention (%)
Charge rate performance	0.25	100.64	99.77
	0.33	100.69	100.1
	0.5	100	100
	1	98.84	100.23
Discharge rate performance	0.25	100.89	101.94
	0.33	100.35	101.03
	0.5	100	100
	1	98.78	97.26

The 314 Ah discharge performance test under different temperatures assesses how varying thermal conditions affect battery capacity and energy retention. The test conditions include charging at 25 °C with 0.5 P to 3.65V, resting, and then discharging at different temperatures ranging from -20 °C to 55 °C, see Figure A 6 and Table A-3. The voltage versus capacity curves indicates that higher temperatures (45 °C and 55 °C) result in higher capacity and energy retention, with retention rates over 100%. Conversely, at lower temperatures (-10 °C and -20 °C), performance decreases, with capacity retention dropping to 95.5% and 96.6%, and energy retention to 81.0% and 85.9%, respectively. DNV notes that the cell's operational temperature ranges from 0 °C to 60 °C, highlighting that optimal performance is achieved within this range. The data matches DNV expectations.

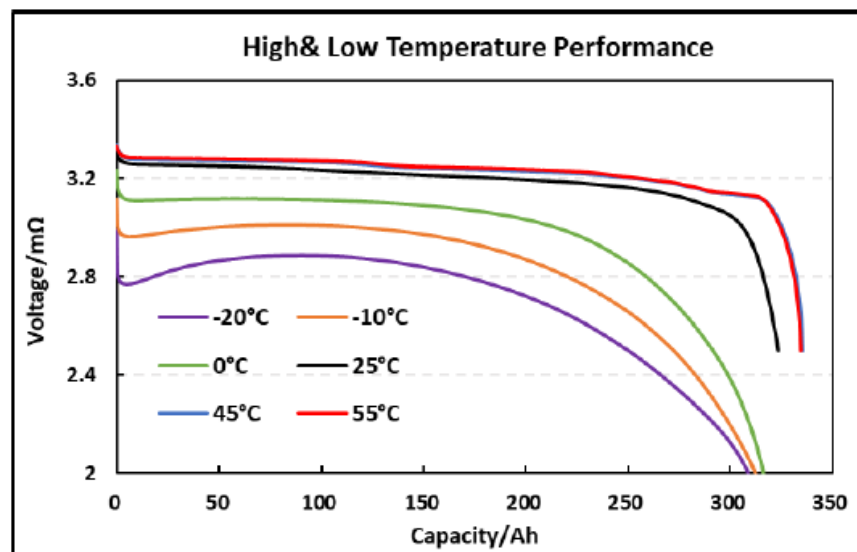


Figure A 6 Discharge performance at 0.5P vs temperature

Table A-3 Discharge performance at 0.5P vs temperature

Temp. (°C)	Capacity retention (%)	Energy retention (%)
-20	95.5	81

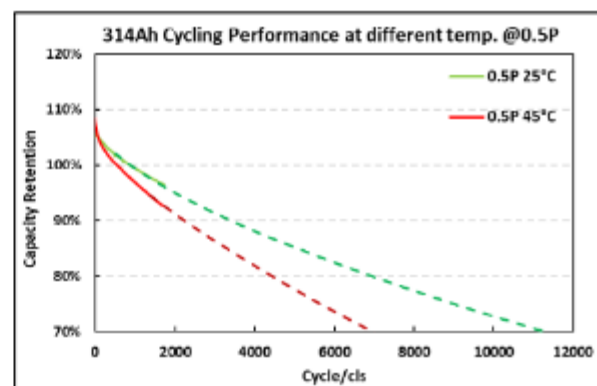
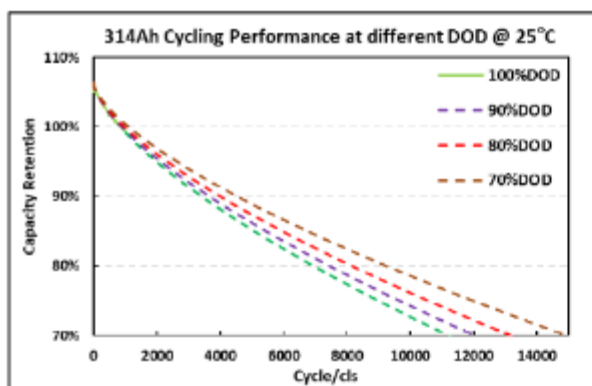
Temp. (°C)	Capacity retention (%)	Energy retention (%)
-10	96.6	85.9
0	97.8	91.1
25	100	100
45	103.7	104.9
55	103.4	104.7

A.3.3 Degradation

A.3.3.1 Cycle life and capacity retention

Cyclic degradation in batteries refers to the loss of capacity and efficiency and increase in internal resistance that occurs with repeated charging and discharging cycles. Temperature plays a critical role in this process; higher temperatures can accelerate degradation by increasing the rate of side chemical reactions within the cell. The rate of charging and discharging also influences cyclic degradation, as higher rates can lead to quicker deterioration. Additionally, the depth of discharge (DOD) range affects cyclic life; typically, batteries cycled deeply (near 100% DOD) degrade faster. The test results illustrate that as expected higher DOD, temperatures, and rates accelerate the degradation of battery cells, underscoring the importance of optimizing these parameters to prolong battery life and maintain performance [146].

The 314 Ah cycling performance test evaluates battery capacity retention under various conditions, including different depths of discharge (DOD), temperatures, and charge/discharge rates, see Figure A 7. The first graph shows that cells cycled at a larger DOD degrade more rapidly than those at smaller DODs, with capacity retention decreasing faster at 100% DOD compared to 70% DOD. The second graph illustrates the impact of temperature, indicating that cells cycled at a higher temperature (45 °C) degrade more quickly than those at a lower temperature (25 °C). The third graph highlights the effect of charge/discharge rates, showing that higher rates (1 P) lead to more rapid degradation compared to lower rates (0.25 P). The data matches DNV expectations.



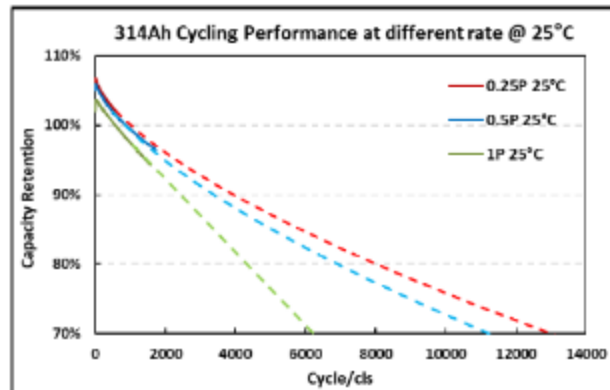
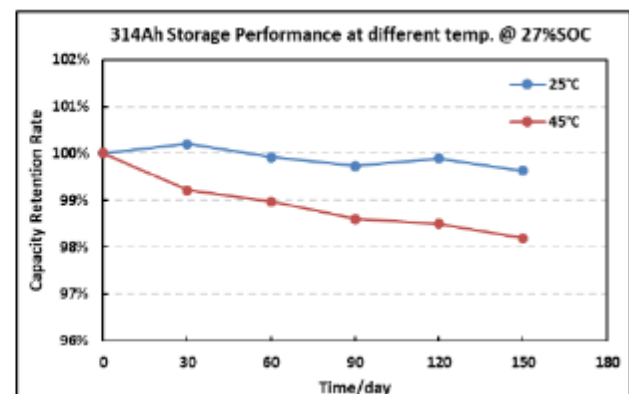
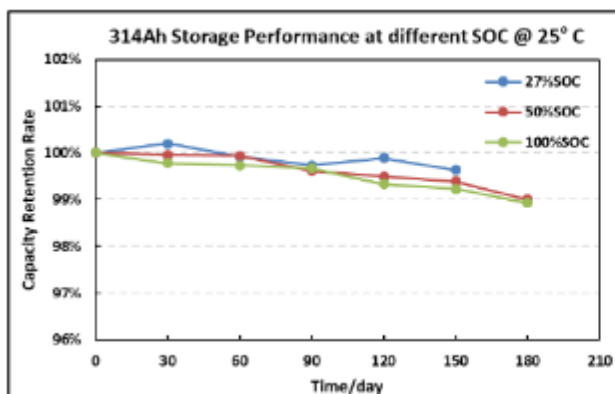


Figure A 7 Cyclic aging behavior at various temperatures, rates and SOC

A.3.3.2 Calendar degradation

Calendric degradation refers to the loss of battery capacity and efficiency over time, regardless of cycling activity, primarily due to chemical changes within the cell during storage. The degree of calendric degradation is significantly influenced by the SOC at which the battery is stored and the ambient temperature. The test results illustrate the impact of SOC and temperature on battery performance, with higher SOC and temperatures leading to more rapid capacity loss over time [146].

The 314 Ah storage performance test evaluates battery capacity retention under various SOC and temperatures, see Figure A 8. The first graph shows that generally cells stored at a higher SOC (100% and 50%) degrade more rapidly than those at lower SOC (27%) at 25 °C. The second graph indicates that cells stored at a higher temperature (45 °C) degrade faster than those stored at 25 °C at 27% SOC. The third graph similarly shows accelerated degradation at 45 °C compared to 25 °C at 100% SOC. This data matches DNV expectation and illustrates that optimizing battery storage conditions can maximize lifespan.



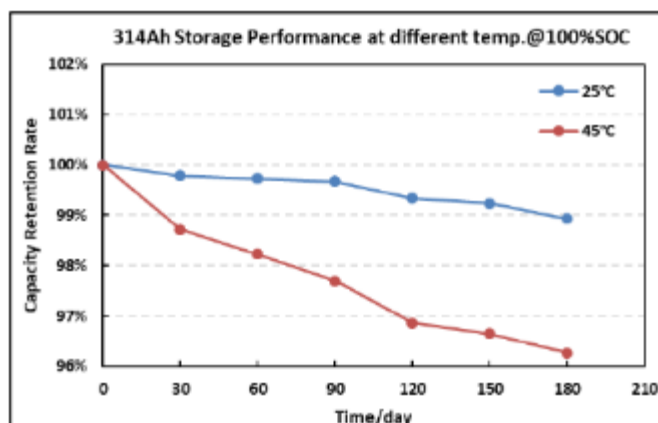


Figure A 8 Calendric aging behavior at various temperatures and SOC

A.4 Thermal management system

A.4.1 Thermal performance

e-STORAGE provided both a static CFD of SolBank 3.0 and transient analysis of average and maximum temperatures. DNV values both static and transient thermal analysis for the different types of evaluation information that can be gleaned from each. A static model allows visualization of whole assemblies or systems to provide insight into heat and fluid flows and identification of hotspots. On the other hand, a transient analysis tracks the thermal behavior over time which shows the interaction between cell or pack heat generation and the chiller cooling effects and most importantly: the duration for which cells are kept above their optimal temperatures.

DNV reviewed SolBank 3.0 pack level CFD report at 0.5 and 0.25P-rate leveraging Hithium's 314 Ah battery cell. The boundary conditions simulation setup: the inlet flow rate was set at 10 L/min. The inlet temperature of the coolant was maintained at 20 °C, while the ambient temperature around the pack was 45 °C. The convective heat transfer coefficient is specified as 5 W/(m² °C), which indicates the efficiency of heat transfer between the battery cell and its surroundings.

A high-level summary of static thermal performance input assumptions is presented in Table A-4. The generation heat of the cell was 14.175 W at the beginning of life (BOL). Additionally, the volume heat flux for the aluminum busbars was provided, with busbar (1) having a flux of 69,756 W/m³ and busbar (2) having a flux of 75,690 W/m³, both at 0.5C.

Table A-4 Pack-Level Static thermal performance input assumptions

Factor or Condition	Value
Cell heat generation	14.175 W (BOL)
Ambient temperature	45 °C
Timing of results sampling	Continuous charge and discharge, without rest period

The CFD static results for SolBank 3.0 pack at 0.5P P-rate is shown in Figure A 9.

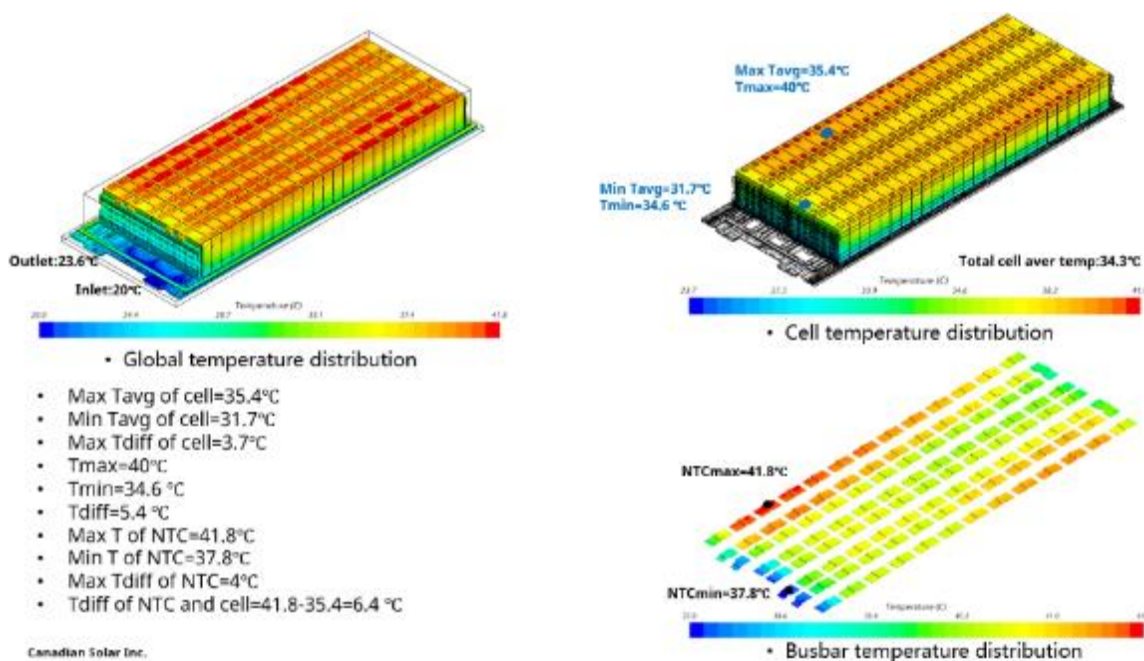


Figure A 9 SolBank 3.0 pack level CFD simulation at 0.5P

The static CFD results for SolBank 3.0 pack at 0.5P show a temperature gradient characteristic typical of liquid cooled modules. The hottest temperatures are at the top of the cells, furthest from the cold plate. DNV notes the busbar temperature distribution is less uniform than the cells, however DNV takes no exceptions here. Figure A 9 indicates the largest temperature differential between the cells is 3.7 °C, indicating some variation in temperature across the pack. DNV views a temperature differential of <4 °C as favorable and in line with expectations.

DNV also reviewed the 0.25P static simulation at the pack level. The resulting cell temperature difference (2.7 °C) was improved, as expected, from the more strenuous 0.5P simulation.

In addition to the pack-level simulation above, DNV also reviewed a static CFD for the full SolBank 3.0 (at 0.25P and 0.5P, and at both BOL and EOL). The CFD setup is presented in Figure A 10. The container has 12 racks and 1 chiller, 4 packs per rack and each pack consists of two 1P52S packs.

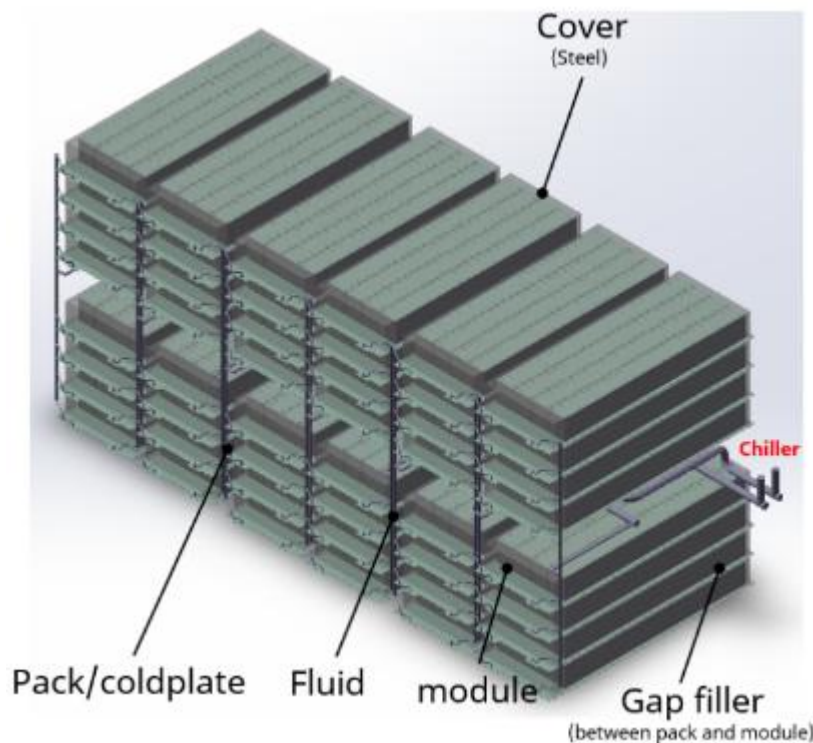


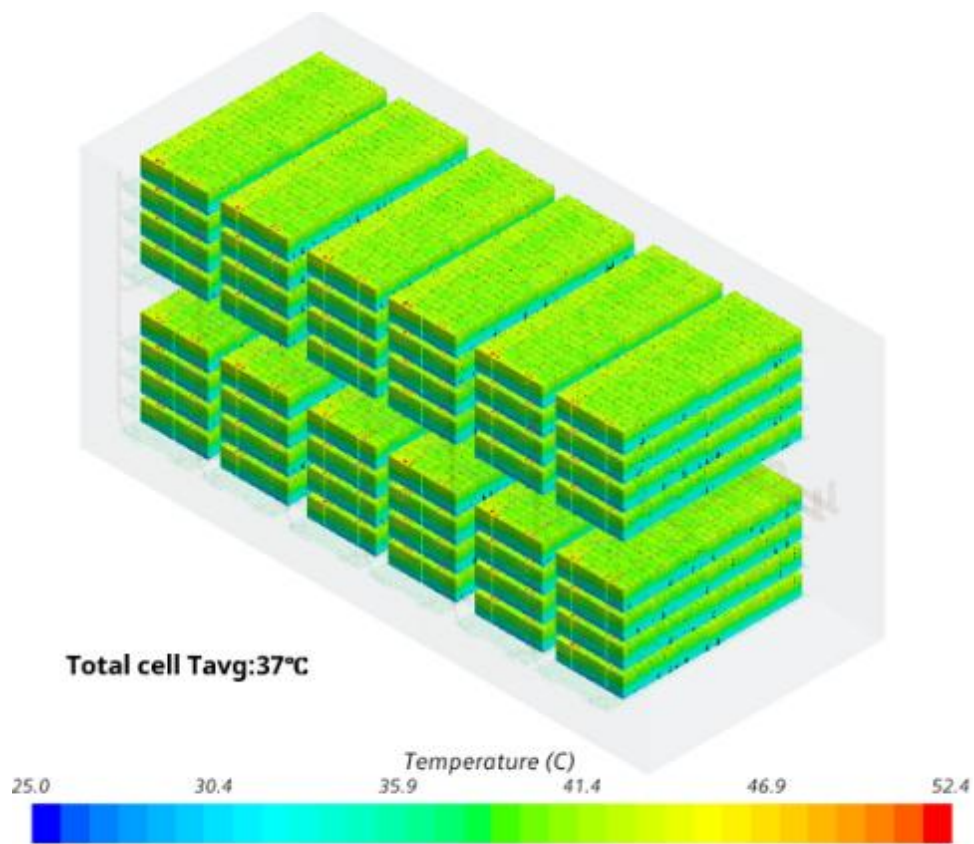
Figure A 10 SolBank 3.0 unit level CFD modelling setup

The boundary conditions simulation setup: the inlet flow rate was set at 480 L/min. The inlet temperature of the coolant was maintained at 20 °C, while the ambient temperature around the system was 25 °C. The generation heat of the cell was 14.175 W at the beginning of life (BOL) at a 0.5P discharge rate. The heat generation of the aluminum busbar was 4W at BOL and at 0.5C. High level summary of static thermal performance input assumptions are presented in Table A-5

Table A-5 Enclosure-Level Static Thermal Performance Input Assumptions at 0.5P

Factor or Condition	Value
Cell heat generation: BOL	14.175 W
Cell heat generation: EOL	18.43 W
Ambient temperature	25 °C
Timing of results sampling	Continuous charge and discharge, without rest period

CFD static results at EOL for SolBank 3.0 at 0.5P-rate (which DNV considers to be the worst case scenario) is shown in Figure A 11.



- Cell temperature distribution

Figure A 11 SolBank 3.0 static CFD simulation at EOL – 0.5P

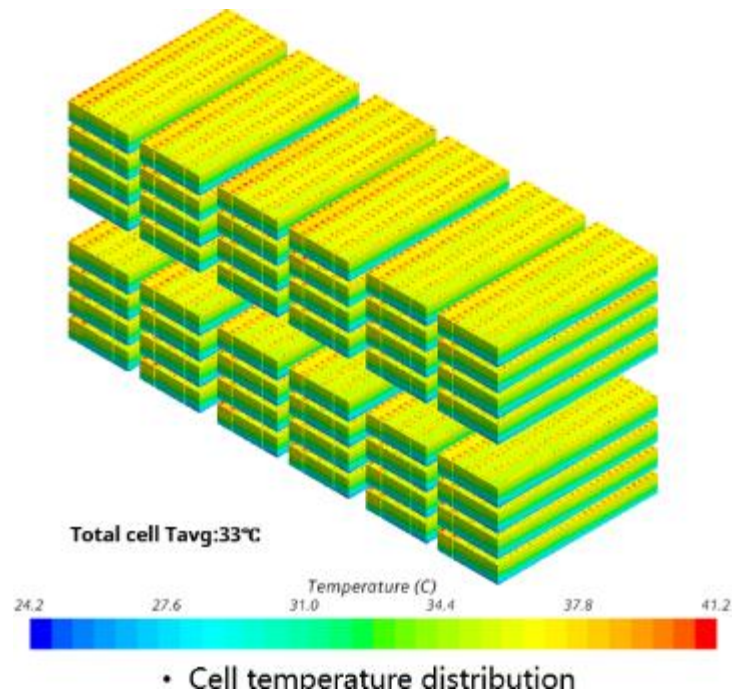


Figure A 12 Static CFD (full BESS) cell temperatures at 0.5P, BOL

While DNV focused on the worst-case EOL for the 0.5P simulation, DNV focuses below on the more favorable BOL simulation to show a best-case comparison (while still at the strenuous 45 °C ambient temperature). The inputs for the 0.25P simulation are the same as shown in Table A-5 except that the cell heat generation at BOL is 4.74 W and at EOL is 6.2 W. Figure A 13 shows the static CFD simulation for the full BESS at 0.25P and BOL.

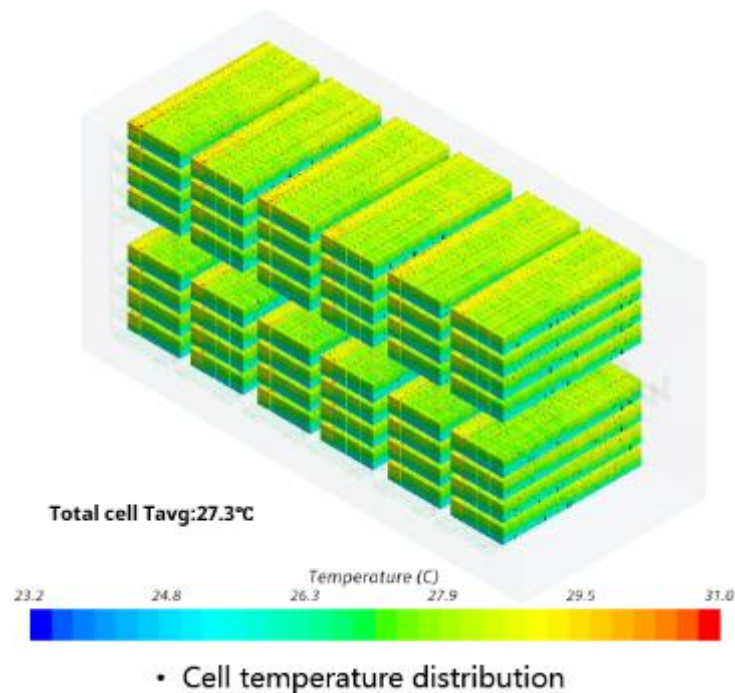


Figure A 13 Static CFD (full BESS) cell temperatures at 0.25P, BOL

The static CFD results for SolBank 3.0 at 0.5P and EOL show a relatively uniform temperature distribution from one module to the next. The highest temperatures (above 50 °C) appear to be points of contact with the busbar and only at the very front of the module, which DNV does not take exception to. The temperatures at the top of the cells appears to generally show low variability across the BESS.

The 0.5P simulation results at BOL, found in Appendix A herein, show a similar temperature pattern to the EOL simulation above. However, the BOL's resulting average and maximum cell temperatures were improved, as expected, from the more strenuous EOL simulation.

Similar to the 0.5P simulations, CSI provided DNV with both BOL and EOL for the 0.25P use case simulation. The temperature distribution characteristic results of the 0.25P case were similar to the 0.5P (with an expected improvement in cell average and maximum temperatures). The results of the 0.25P simulation at BOL are found in Appendix A herein. DNV considers static CFD of both 0.25P and 0.5P to be in line with industry expectations. Notably, these results do not account for the duration at higher temperatures, which is a critical factor in battery degradation. This aspect is reviewed in the transient analysis below.

The SolBank 3.0-0.5P system liquid cooling transient test involved a detailed setup, presented in Figure A 14. Sensors placed on the equipment surface and within the packs at the cell level to monitor temperature. The test was conducted at 0.5P, where the system was charged at 2.35 MW until a cut-off condition of 3.6V was reached, followed by immediate discharging at 2.35 MW until a cut-off condition of 2.8V, repeated for three cycles. The ambient temperature during the test was not specified in the provided section of the document, which is crucial for understanding the thermal performance.



Figure A 14 SolBank 3.0 transient liquid cooling testing setup

Table A-6 outlines transient thermal performance input assumptions. The state of charge (SOC) cycling profile is provided, whereas, a 2-hour charge followed by a rest period and then a 2-hour discharge and repeated for several cycles.

Table A-6 Thermal performance transient data input assumptions

Factor or Condition	Value
Ambient temperature	35 °C
Solar radiant load included?	No
SOC cycle tested	2-hour charge, rest, and 2-hour discharge
Rest period duration	none

The temperature profile of SolBank 3.0 during a charge-discharge test is presented in Figure A 15 and Figure A 16. Both figures represent the results for the test of Figure A 14. Figure A 15 is the big picture showing current, temperatures (Tmax, Tmin, and Tdiff) over the course of the test and snapshots of the NTC temperature (maximum, average, temp reading during duration of test). DNV notes that the NTC reading represents the busbar temperature rather than the cell temperature. The results of the 0.5C charge-discharge cycle test for 'Rack 1' with an inlet temperature of 20 °C are presented in Figure A 15

and Figure A 16. The scatter plots below the main graphs provide a detailed view of the temperature for different points (T36, T141, T192, and T168) on the battery cells. These plots show two distinct clusters of data points, representing temperatures at the end of the first discharge and the end of the second charge.

Figure A 15 and Figure A 16 show the internal temperatures of the cells in Rack 1 over time. The temperature fluctuates in response to the charging and discharging cycles, with the highest temperature reaching 38 °C. The current flow through Rack 1 during the same period, showing corresponding peaks and troughs that align with the temperature changes.

Figure A 15 and Figure A 16 shows three lines representing the temperature over time, with one line indicating the temperature of the system's cell and the other showing the ambient temperature. Maximum temperature during the charge and discharge cycle is 40 °C. Additionally, the maximum temperature difference (Tdiff) of SolBank 3.0 is 9 °C during the same cycle.

DNV notes that the cycling duty is very thermally strenuous, once it really starts (according to their notes about 2:10:00) it is continuous repeated cycling with very short (or no) rest. DNV considers this significantly more thermally strenuous than likely deployment scenarios and favorable to produce conservative temperature predictions. However, it is not clear to DNV what the ambient temperature of the test is which significantly impacts the chiller's capacity. Thus, DNV is unable to opine on risk of accelerated capacity degradation.

Overall, DNV considers SolBank 3.0's static and transient performance to be in line with industry expectations.

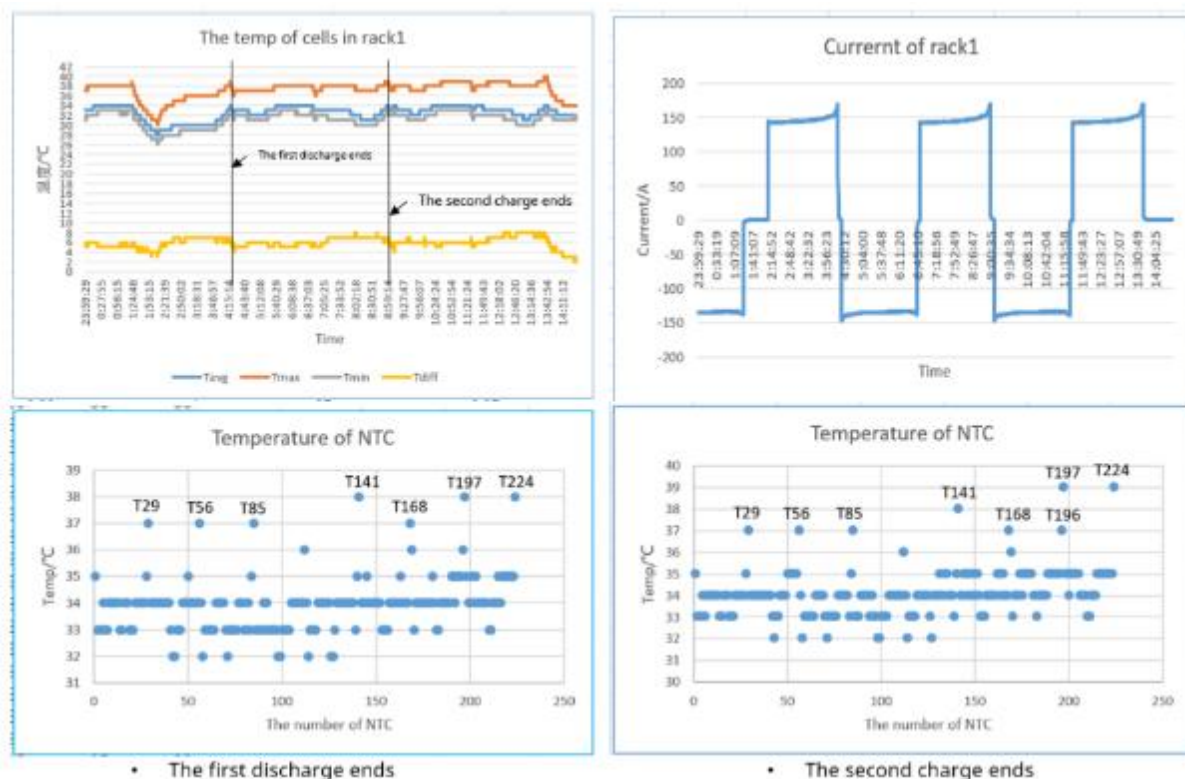


Figure A 15 Rack 1 charge-discharge cycle at 0.5C

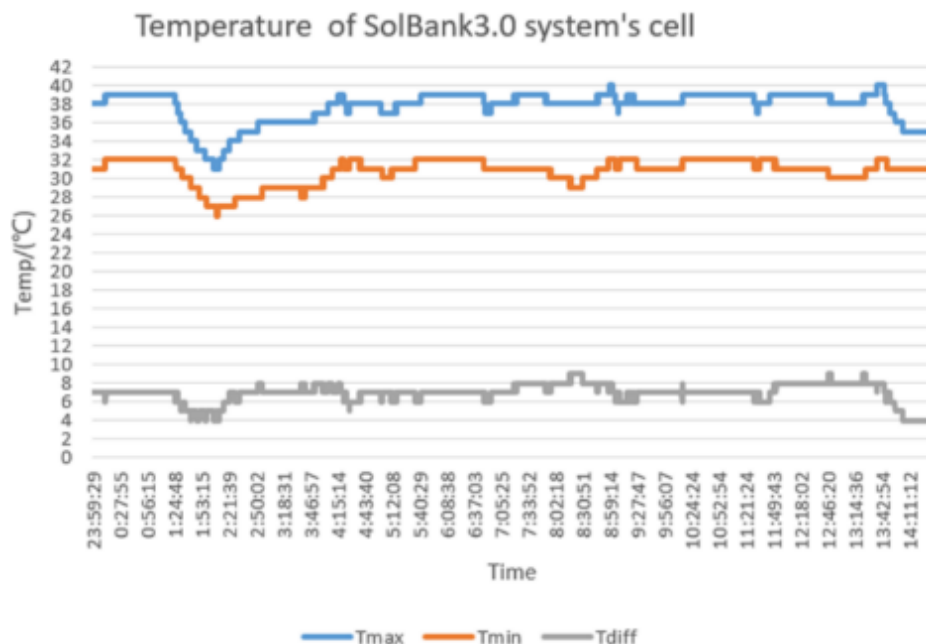


Figure A 16 0.5C Tmax, Tmin, and Tdiff during charge-discharge cycling

A.5 List of IEC test report and certificates

SolBank 3.0 holds the following additional test reports and certificates:

Table A-7 IEC test reports and certificates list (Hithium cell)

Component	Test standard	Certification/Test verified
Cell	IEC 62619	The Hithium cell model # LFP71173207/314Ah has obtained CB test certificate issued by TUV Rheinland [148].
Cell	IEC 62321	The Hithium cell model # LFP71173207/314Ah has obtained IEC 62321 certificate issued by Shenzhen Tiansu Calibration and Testing Co. Ltd [149]
Unit	IEC 63056	The unit model # CSI-SolBank-R-418-2h-H has obtained IEC 63056 certificated issued by TUV SUD Product Service GMBH [150]
Unit	IEC 62619	The unit model # CSI-SolBank-R-418-2h-H and CSI-SolBank-R-418-4h-H have obtained IEC 62619:2022 (IEC 63056:2020) certificate issued by TUV Rheinland [151]
Integrated BESS	IEC 62477	The BESS model # CSI-SolBank-S-5016-2h-EU and CSI-SolBank-S-5016-4h-EU (Hithium cell) have obtained IEC 62477 certificate issued by TUV Rheinland [152] [153] [154] [155] [156] [157]
Integrated BESS	IEC 61000	The BESS model # CSI-SolBank-S-5016-2h-EU, CSI-SolBank-S-5016-4h-EU (Hithium cell) have obtained IEC 61000-6-2:2019 certificate issued by TUV Rheinland [158] [159]
Integrated BESS	IEC 62933	The BESS model # CSI-SolBank-S-5016-2h-EU (Hithium cell) has obtained IEC 62933-5-2:2020 test report issued by TUV SUD [160]

A.6 UL 9540A testing

DNV has received 4th edition testing of the cell, module, and unit level for SolBank 3.0.

A.6.1 Cell-level results

Hithium Battery has tested its lithium-ion cell, model LFP71173207/314Ah, to the 4th edition of UL 9540A test methodology. TUV Rheinland, a nationally recognized test lab (NRTL), conducted this test on 12 June 2023 [55]. The cell is a prismatic LFP type battery with 314 Ah capacity. At the cell level, the methodology tests whether thermal runaway can occur in a single cell and provides insights into onset temperatures for venting and thermal runaway, off-gas composition and off-gas volume. To provide comparison and benchmarks, DNV has reviewed test reports for cells that were conducted under the same or similar conditions for cells with similar chemistry, capacity and form factor.

Test method and deviations: DNV did not identify deviations from the test method described in UL 9540A. The cell level UL 9540A report outlines the test method and results in a manner that is consistent with the requirements of UL 9540A 4th edition, section 7.

Venting and thermal runaway temperatures: The cell venting and thermal runaway onset temperatures were noted as 203.7 °C and 295.7 °C, respectively. DNV notes that the cell venting and thermal runaway temperatures are higher than what DNV has typically seen for LFP battery chemistry. The Hithium cell displayed ~90 °C between the temperature at cell venting and thermal runaway. DNV views the wide cell venting and thermal runaway temperature difference as beneficial for the cell as there is more of an inherent barrier in place for increasing temperatures and may provide enough time for safety systems to detect and respond to thermal events.

Gas composition and volumes: In comparison with other tests DNV has reviewed that were conducted under the same or similar conditions, the gas composition reported for the Hithium cell has a high proportion of H₂. In general, the high amount of hydrogen produced could qualitatively relate to an energetic explosion, although a detailed quantitative analysis of this data would be necessary to determine the impact. A total of 130 L of gas was produced during the test. The volume of gas produced was lower on a per-amp-hour basis. This may be a product of the form factor of the cell but would contribute favorably to the safety of the cell.

Performance criteria: DNV notes that the UL 9540A test method stipulates that the cell level test should meet the following two performance criteria: thermal runaway should not be induced, and an off-gassing event should not produce flammable gases. Since flammable gases were produced and the cell experienced thermal runaway, the cell level test did not meet the performance criteria. Hence, module level testing was performed. This is expected of cells using lithium-ion chemistry.

A.6.2 Module-level results

CSI has tested its lithium-ion battery module, model CSI-SolBank-P-104.5-2h-H, CSI-SolBank- P-104.5-4h-H, to the 4th edition of UL 9540A test methodology. TUV Rheinland, a nationally recognized test lab (NRTL), issued the module level test report [56].

Test method and deviations: DNV found the test to have been conducted in line with the UL 9540A standard's methodology.

Observation: The test results indicated that no fire, flames, flying debris, explosive discharge, sparks, electrical arcs or re-ignitions observed. DNV notes that per the module level test report, three cells were initiated and cell-to-cell thermal runaway propagation occurred to two additional adjacent cells. However, Figure A 17 indicates that one cell was placed

under heaters on both larger surface sides of the cell. Therefore, it will be interpreted as one cell was initiated with two heaters and cell-to-cell propagation occurred to four additional adjacent cells.



Figure A 17 Initiating cell and heaters location in battery module

In addition, the test report stated that 262.16 L of hydrogen, 157.10 L of carbon monoxide, 388.98 L of carbon dioxide and 285.55 L of hydrocarbons gases were generated during the test. Hydrogen and hydrocarbons, such as methane and propane, are explosive and flammable gases. In addition, carbon monoxide is an extremely flammable gas that can readily form an explosive mixture with air. Carbon dioxide is also an asphyxiant. DNV considers it best practice to utilize the module level results to validate the safety design features in the BESS. More detailed information regarding the safety features is included in Section 5.7.3.2 herein.

Performance criteria: DNV notes that the UL 9540A test method stipulates that the module level test should meet the following two performance criteria: thermal runaway should be contained within module, and an off-gassing event should not produce flammable gases. Since flammable gases were produced in cell level testing, the module level test did not meet the performance criteria. Hence, the unit level test was conducted.

A.6.3 Unit-level results

e-STORAGE has tested their BESS Unit, model #CSI-SolBank-R-418-2h-H, CSI-SolBank-R-418-4h-H, to the 4th edition of the UL 9540A test methodology. DNV reviewed the unit level test report conducted by TUV Rheinland [57].

Unit description: For the purposes of the test, a Unit was considered an open rack without enclosure consisting of 4 modules plus 1 control box. Figure A 18 displays the location of initiating module during the test.

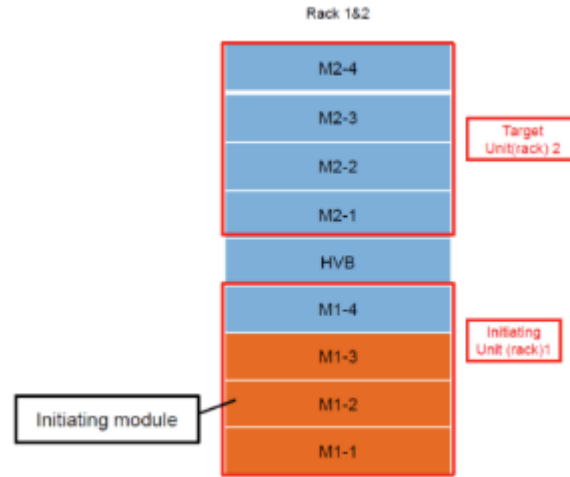


Figure A 18 Initiating unit and target unit location during the UL 9540A test

Test method and deviations: In the Unit level test, a complete BESS Unit is installed and surrounded by target (dummy) BESS and walls at the distance intended in its installation. Thermal runaway is induced in battery cells of one of the modules in the initiating BESS Unit. The results are intended to report whether a fire or thermal runaway will propagate between modules and other Units, and whether there will be flying debris or explosive discharge of gas. The 4th edition UL 9540A unit-level methodology outlines procedures for different types of installation including indoor and outdoor ground mounted systems. The test report indicates this unit has been tested for non-residential indoor ground mounted use.

The following provides an overview of the test set up:

- Three instrumented walls (at least 0.61 m taller than unit height and 0.49 m extended up to exterior target unit) were constructed to form a perimeter around three sides of the initiating and target units. The walls were constructed covered with 16 mm gypsum wall board and painted flat black.
- 4 Units/racks were used for this test (see Figure A 19 for arrangement).
- The minimum separation distance from the unit to wall and between units is displayed in Figure A 19. Customer indicated that the separation distance between the initiating unit and target unit is 601 mm [161].

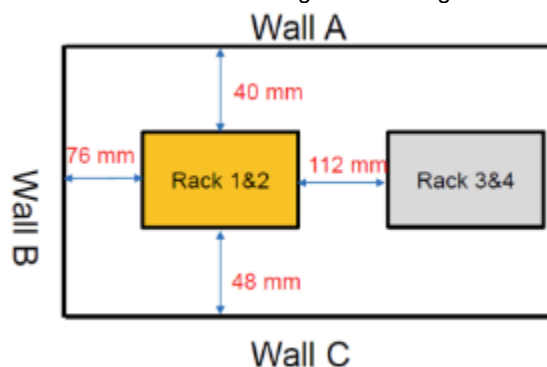


Figure A 19 UL 9540A unit level test setup

Observations and performance criteria: During the tests, no flaming explosive hazards, including deflagration or detonation, were observed. Furthermore, during the test no flying debris, sparking, electrical arcs, or other electrical events occurred or were observed. An electrolyte leak was observed after the test. A total of 174.19 L of hydrogen, 104.63 L of carbon monoxide, 427.33 L of carbon dioxide and 268.04 L of hydrocarbons gas were measured during the test.

DNV notes that per unit level test report, three cells initiated in initiating battery module and cell-to-cell thermal runaway propagation occurred to two additional adjacent cells. However, Figure A 20 indicates that one cell was placed under heaters on both larger surface sides of the cell. Therefore, it should be interpreted as one cell was initiated with two heaters and cell-to-cell propagation occurred to four additional adjacent cells. Module-to-module thermal runaway propagation was not observed during the test.



Figure A 20 Initiating cell and heaters location in battery module

Table A-8 provides an overview of the performance conditions set forth by UL 9540A in addition to the summary of the Unit test observations.

Table A-8 UL 9540A Unit performance criteria for indoor floor mounted BESS (Hithium cell)

Performance condition	Test observation/remark
Flaming outside the initiating BESS unit is not observed	Meets the performance criteria. No flaming was observed internally or externally of the Unit during the test.
Surface temperatures of modules within the <u>target</u> units adjacent to the initiating unit do not exceed the temperature at which thermally initiated cell venting occurs, as determined in 7.3.1.8.	Meets the performance criteria. The maximum surface temperature measured on modules inside the target Unit was 27.6 °C, far below the cell venting temperature of 203.7 °C reported in the cell-level test.
For units intended for installation in locations with combustible constructions, surface temperature measurements on wall surfaces do not exceed 97 °C of temperature rise above ambient temperature per 9.2.15.	Meets the performance criteria. The maximum surface temperature on the adjacent walls was 41.3 °C, below the 97 °C temperature rise performance criteria.
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.	Meets the performance criteria. Explosion hazards were not observed during the test (internal and external).
Heat flux in the center of the accessible means of egress shall not exceed 1.3 kW/m ²	Meets the performance criteria. Maximum heat flux detected was roughly 0.5 kW/m ² .

Module-to-module and unit-to-unit propagation were not observed during testing. The outlined performance criteria have been met, indicating the separation distances used during testing provides an adequate thermal barrier between modules

and therefore can be used as the minimum separation distances for installation. The Unit level results show a resiliency of the Unit to thermal runaway propagation and fire hazard in a single failure event.

A.7 Explosion prevention

Methodology: The explosion/deflagration prevention system is designed to reduce the concentration of flammable gas inside the BESS enclosure below 25% LFL by means of a ventilation system. Systems that employ this methodology are required to comply with NFPA 69 design guidelines (Standard on Explosion Prevention Systems).

System description: Although the enclosure dimensions result in a total volume of 31.38 m³, subtracting out the internal components of the cabinet results in an open volume for air of 8.74 m³. The ventilation system is comprised of 2 hydrogen gas sensors and a ventilation system which includes 1 exhaust fan and 2 motorized louver intakes, as displayed in **Figure 5-16**. The exhaust fan is manufactured by Nanjing Heben M&E Equipment Technology Co., Model #: TPF13, TPF14; size: 410x360 mm with a rated ideal air flow capacity of 1390 m³/h (820 CFM). The report states that due to the flow restriction of the components inside the container the fan operates at 1020 m³/h (600 CFM). 1020 m³/h was the flow rate used to run the CFD calculations. DNV finds the noted reduction in flow from ideal to actual to meet expectations.

When a Level-1 gas detection alarm (concentration above 10% LEL) occurs the ventilation system opens the intake louvers and operates the exhaust fan to purge the battery cabinet with ventilation.

Design compliance: Systems that employ methodology described above are required to comply with NFPA 69 design guidelines (Standard on Explosion Prevention Systems). DNV reviewed a CFD analysis report [162] which demonstrates the deflagration prevention system's performance using NFPA 69 guidelines through a set of documented technical assumptions.

The CFD simulation was accompanied by the UL 9540A 4th edition cell, module and unit level test results of SolBank 3.0 associated with Hithium cell model # LFP71173207/314Ah which includes the flammable gas concentration, number of cell's failure and gas release rate. Based on UL 9540A test results, a total 5 cell's failure scenario resulting in a total of 116.5 LPM gas release rate was assumed in the CFD simulation. The gas release rate kept constant throughout the simulation as a conservative approach. DNV views the flow modeling decisions to follow reasonable engineering judgement.

Furthermore, 3 gas release positions are identified as at the bottom module of the left rack, middle rack, and right rack of the enclosure. DNV finds the assumptions regarding the gas release positions to be effective for the conservative analysis, as the detection location was furthest from the gas release location which introduced delay in detecting. Additionally, this setup is helpful in evaluating the performance of the fan in removing flammable gases from the bottom surfaces.

DNV notes these technical assumptions, gas release location, gas release rate and reduced air flow rate are reasonably above and beyond the scenario described in UL 9540A testing, and views them favorably.

The simulation results indicate that the ventilation system can maintain the flammable gas concentration below 25% of LFL for all 3 modeled cases and therefore meets the requirements of NFPA 69.

A.8 Explosion protection

Methodology: Explosion protection for this BESS is achieved through deflagration venting as described in NFPA 68:2023, Chapter 6. In simple terms, if flammable gases released during a battery thermal runaway event ignite inside the sealed container, lightweight vent panels (rupture diaphragms) mounted on the enclosure walls burst open at a preset pressure (0.1 bar-g), allowing the expanding combustion gases and pressure to escape outward before the internal pressure exceeds the structural capacity of the container. The design objective is to ensure that the reduced explosion pressure inside the

enclosure (P_{red}) remains below a safe fraction of the container's ultimate structural strength, thereby preventing catastrophic failure.

System Description: SolBank 3.0 is housed in a container with approximate external dimensions of 6.058 m × 2.438 m × 2.896 m. To provide deflagration venting, the enclosure is equipped with five roof-mounted deflagration vent panels manufactured by BasCo, each with dimensions of 610 mm × 610 mm with a static activation pressure (P_{stat}) of 0.100 bar. The use of certified, commercially available vent panels in contrast to bespoke panels, is a favorable design choice, as they undergo extensive testing and certification, ensuring reliability.

Technical Assumptions: This assessment herein is based on a review of the provided TUV Rheinland Test Report number CN24JLG0001, which performed a Computational Fluid Dynamics (CFD) analysis to evaluate the deflagration venting system against the requirements of NFPA 68:2023. DNV notes that the review and compliance statement is limited to the Hitium cell and does not extend to other cell OEMs used in the product.

Key Technical Assumptions:

- **Fuel Composition:** The flammable gas mixture was based on data from a UL 9540A cell level test report and was primarily composed of hydrogen (49.875%), carbon dioxide (26.861%), and carbon monoxide (16.202%). Using fuel composition data directly from a UL 9540A test of the cells is a credible approach.
- **Enclosure Strength (P_{es}):** The analysis assumes the enclosure can withstand a static pressure of at least 0.55 bar-g. DNV has not verified this value, but opines that it may be higher than typical values for steel enclosures of comparable construction. The conclusion of the report, compliance, and hazard impact is reliant on the accuracy of this unverified input in the CFD analysis.
- **Target Reduced Pressure (P_{red}):** The goal was to ensure the maximum pressure from the CFD simulation remained below the enclosure's calculated dynamic strength limit. The calculated allowable P_{red} for the design was 0.374 bar-g, whereas the simulated pressure was .370 bar-g. The final simulated pressure of 0.370 bar-g against the calculated limit of 0.374 bar-g represents a safety margin of less than 1%, which may be insufficient for deflagration venting systems.
- **Vent Static Activation Pressure (P_{stat}):** The vent panels are assumed to activate at 0.1 bar-g. Which is a typical activation pressure for an engineered vent panel.
- **Failure Scenario:** The simulation modeled a failure scenario involving 5 cells undergoing thermal runaway, per UL 9540A data, releasing a total of 1093.79 L of flammable gas over a 60-second period. Three different ignition locations were modeled to determine the worst-case pressure development. Justifying the 5-cell failure based on UL 9540A test results is a reasonable approach.

Design Compliance: The report concludes that because the maximum predicted pressure from the simulation ($P_{red} = 0.370$ bar-g) is less than the calculated allowable pressure of the enclosure (0.374 bar-g), the design is compliant with NFPA 68 by a strict reading of the standard.

While presented as compliant with NFPA 68, the design's validity is dependent on its reliance on an unsubstantiated assumption of maximum enclosure strength (P_{es}) value and a minimal safety margin for reduced explosion pressure (P_{red}). This approach creates two safety risks: the unverified P_{red} creates uncertainty that the enclosure's structural capacity will not be exceeded, and the minimal safety margin provides low tolerance for process variations.

APPENDIX B – E-STORAGE

DNV leveraged technology review report of e-STORAGE 314 Ah cell for this section [163].

B.1 Company Evaluation

See Section 2 herein for e-STORAGE's company evaluation details.

B.2 Battery cell specifications

Figure B-1 presents prismatic e-STORAGE's 314 Ah LFP cell and specifications are presented in Table B-1, which includes several paraments such as capacity, operating voltage and operating temperature conditions.

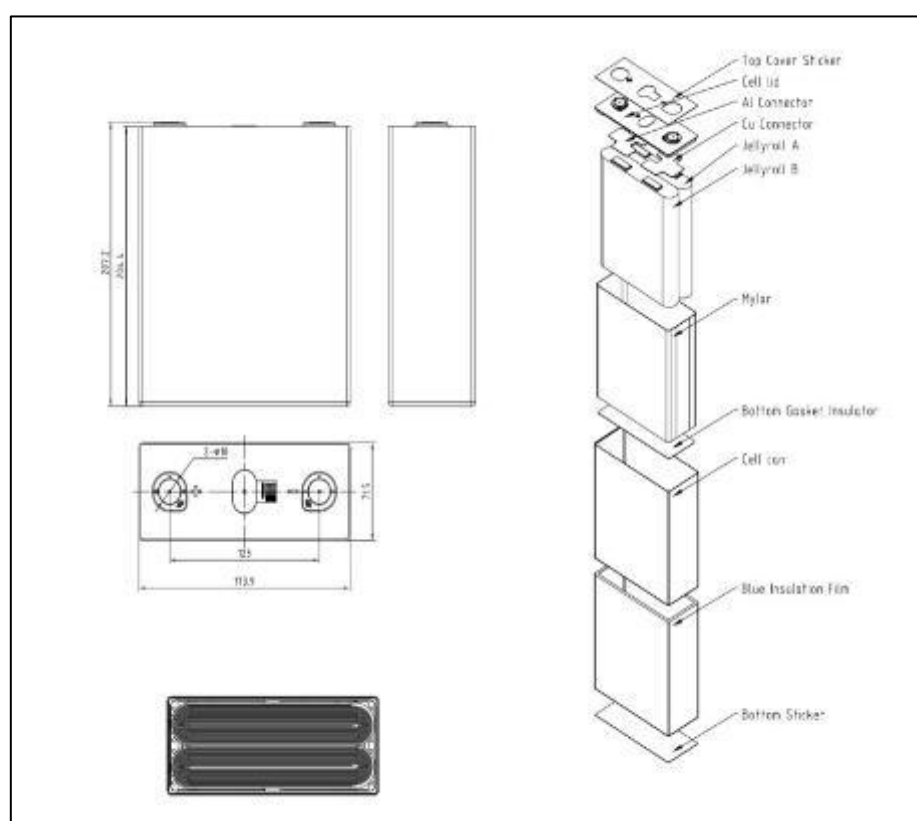


Figure B-1 Product design and drawing of e-STORAGE 314 Ah cell

Table B-1 e-STORAGE's 314 battery cell specifications

Parameter	Specification
Cell type / chemistry	Type: Prismatic Chemistry: LFP
Cell model	CSI 314

Parameter	Specification
Nominal capacity	314 Ah
Operating voltage range	2.5 V to 3.65 V ($T > 0\text{ }^{\circ}\text{C}$) 2.0 V to 3.65 V ($T \leq 0\text{ }^{\circ}\text{C}$)
Nominal voltage	3.2 V
Nominal energy	1004.8 Wh
AC-impedance	$\leq 0.25\text{ m}\Omega$
Maximum charge/discharge current	502 W (0.5P)
Discharge end voltage	2.5 V $T \geq 0\text{ }^{\circ}\text{C}$ 2.0 V $T \leq 0\text{ }^{\circ}\text{C}$
Maximum operating temperature range (Charge)	0 $^{\circ}\text{C}$ to 60 $^{\circ}\text{C}$
Maximum operating temperature range (Discharge)	-20 $^{\circ}\text{C}$ to 60 $^{\circ}\text{C}$
Optimal operating temperature range (Charge)	25 $\pm$ 2 $^{\circ}\text{C}$
Optimal operating temperature range (Discharge)	25 $\pm$ 2 $^{\circ}\text{C}$
Storage temperature (≤ 6 months)	-20 $^{\circ}\text{C}$ to 45 $^{\circ}\text{C}$
Cell dimensions (W x L x H)	71.8 $\pm$ 0.5mm x 173.70 $\pm$ 0.5mm x 204.4 $\pm$ 0.5mm (without terminal)
Weight	5.66 $\pm$ 0.20 kg
Energy density	177.53 Wh/kg

DNV notes that the charge temperature's lower limit is set above 0 $^{\circ}\text{C}$, ensuring that the cells are not charged in freezing conditions. The upper limit, on the other hand, is higher than most, typically not exceeding 55 $^{\circ}\text{C}$. Additionally, DNV has observed that the e-STORAGE 314 Ah cell dimensions differ slightly from those of EVE and Hithium cells. This difference is because e-STORAGE 314 Ah cell specifications are without including the terminal, whereas EVE and Hithium has included terminal in their specifications.

Overall, DNV considers e-STORAGE 314 Ah cell specifications to be in line with similar products in industry.

B.3 Performance evaluation

DNV notes that the following performance data is based on tests performed on e-STORAGE 314 Ah LFP cell, which is utilized in SolBank 3.0.

B.3.1 Capacity

Capacity performance testing is essential for assessing the efficiency and reliability of battery cells. This type of testing involves measuring the charge and discharge cycles under controlled conditions to determine the battery's capacity, and voltage behavior. The results highlight a discharge capacity of around 334.46 Ah, which exceeds the target of 314 Ah, and a discharge energy of 1070.33 Wh, surpassing the benchmark of 1004.8 Wh. This indicates efficient performance under the 0.5P test conditions [163].

e-STORAGE performed cell capacity tests at 5 $^{\circ}\text{C}$, 25 $^{\circ}\text{C}$, and 45 $^{\circ}\text{C}$. The cell was charged at 0.5P constant power to 3.65 V and discharged to 2.5 V with 10 minutes rest between each charge and discharge cycle. The energy efficiency was calculated to be 94.5% for 25 $^{\circ}\text{C}$ and 45 $^{\circ}\text{C}$, and 80% for 5 $^{\circ}\text{C}$. The capacity results are summarized in Table B-2. Higher temperatures (25 $^{\circ}\text{C}$ and 45 $^{\circ}\text{C}$) improve the cell's capacity and efficiency due to enhanced electrochemical reactions. At 5 $^{\circ}\text{C}$, the performance drops, which is typical for LFP cells as lower temperatures slow down these reactions.

Table B-2 Capacity results of e-STORAGE's 314 Ah cell

Cell No.	Temperature	Charge capacity / Ah	Discharge capacity / Ah	Charge energy / Wh	Discharge energy / Wh	Energy efficiency
1	25 °C	333.56	335.12	1129.24	1067.14	94.5%
2	25 °C	334.46	335.97	1131.50	1070.33	94.59%
1	45 °C	336.67	342.73	1135.10	1101.07	97%
2	45 °C	337.08	343.09	1139.11	1098.00	96.88%
1	5 °C	316.48	300.31	1091.10	929.04	84.29%
2	5 °C	319.07	304.63	1098.35	944.48	85.99%

Figure B-2 show the charge and discharge curves of e-STORAGE 314 Ah cell. Tests were conducted at 5 °C, 25 °C, and 45 °C. At 25 °C and 45 °C, the cell exhibits typical charge and discharge plateaus between 3.1 V and 3.3 V, indicating standard electrochemical behavior with minimal side reactions during charging and discharging. The discharge capacity at these temperatures exceeds the rated capacity. However, at 5 °C, the discharge capacity is slightly below the rated capacity, which is a common characteristic of LFP cells. DNV has reviewed the charge/discharge capacity results favorably and consider it in line with similar products in industry.

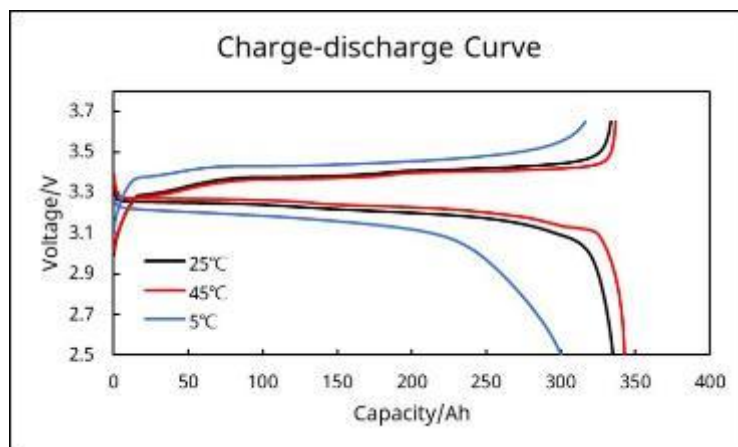


Figure B-2 Charge and discharge curves of e-STORAGE's 314 Ah cell

B.3.2 Power capability and duration

Rate capability in batteries refers to their ability to charge and discharge at different rates without significant performance loss. Temperature significantly impacts this, as higher temperatures typically enhance power capabilities by lowering internal resistance. C-rate indicates the speed at which a cell is charged from 0% SOC to 100% SOC or discharged from 100% SOC to 0% SOC. For example, a 0.5C discharge rate means it takes two hours to fully charge the cell from a fully discharged state.

For cells designed for ESS applications, cell manufacturers more commonly characterize the cells by using constant power rate (P-rate).

e-STORAGE's 314 Ah cell is tested under 0.5P and 1.0P, and combination of both. The test procedures are summarized as follows:

- 0.5P: 25 °C; 0.5P charge to 3.65 V; 10 minutes rest; 0.5P discharge to 2.5 V
- 1.0P: 25 °C; 1.0P charge to 3.65 V; 10 minutes rest; 1.0P discharge to 2.5 V
- 1.0P/0.5P: 25 °C; 1.0P charge to 3.65 V; 10 minutes rest; 0.5P to 3.65 V; 10 minutes rest; 1.0P discharge to 2.5 V; 10 minutes rest; 0.5P discharge to 2.5 V

The rate performance test results are summarized in Table B-3.

Table B-3 Power capability results of e-STORAGE's 314 Ah cell

Cell No.		1			2	
Rate	0.5P	1.0P/0.5P	1.0P	0.5P	1.0P/0.5P	1.0P
Charge energy (Wh)	1130.22	1141.30	1151.34	1135.43	1149.50	1159.73
Discharge energy (Wh)	1070.99	1057.05	1059.65	1075.56	1062.23	1056.98
Energy efficiency	94.76%	92.62%	91.34%	94.73%	92.41%	91.14%

DNV considers that at high C-rates (1C) the discharge capacity of the cell exceeds the rated discharge capacity.

DNV also notes that at a 1.0P charge rate, the charge energy is higher than that tested at 0.5P, likely due to the heat generated by the cell at a higher charge rate. However, the discharge energy at 1.0P is lower than that tested at 0.5P, resulting in lower energy efficiency. DNV observes that these characteristics are typical for cell products.

It is not clear from the provided information whether one cell was used for all three test conditions or if multiple cells were used.

The test procedure is as follows: 0.5P charge to 3.65 V, followed by a 30-minute rest; 0.5P discharge to 2.5 V, followed by another 30-minute rest; then 0.25P charge to 3.65 V, followed by a 30-minute rest; and finally, 0.25P discharge to 2.5 V. These steps are to be conducted at ambient temperatures of 15 °C, 20 °C, 25 °C, 30 °C, 35 °C, and 45 °C.

e-STORAGE tested its 314 Ah cell under various temperatures across 45 °C to 15 °C by using 0.5P and 0.25P P-rates, see Figure B-3.

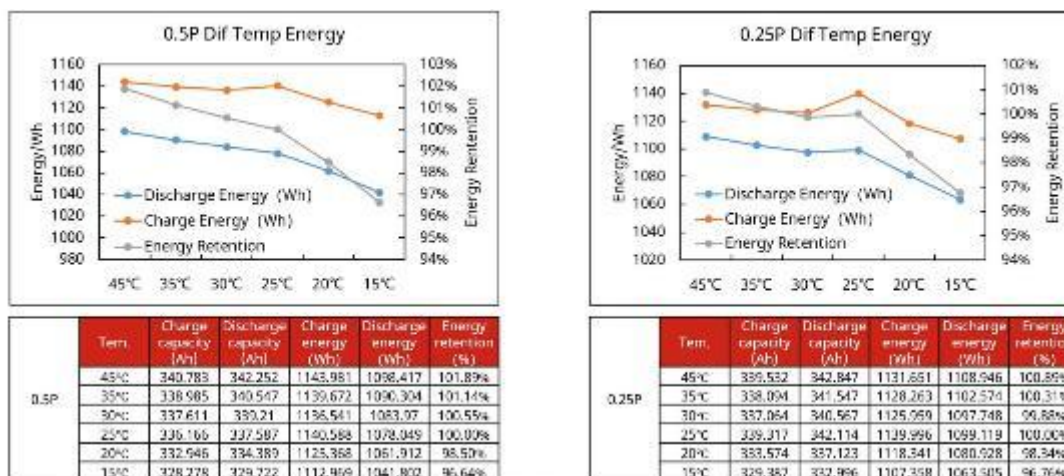


Figure B-3 High and low temperature test results of e-STORAGE's 314 Ah cell

DNV looks favorably on the test results presented in Figure B-3, as both the discharge capacity and discharge energy exceed the rated parameters across the tested temperature range.

B.3.3 Degradation

B.3.3.1 Cycle life and capacity retention

Cycle life performance, or degradation, is a measure of cell's product life under certain operating conditions. The indicator of the cycle life performance is the capacity retention, which is calculated as the ratio of discharge capacity of any cycle to the initial discharge capacity at the fresh state. This measure is often known as the state of health.

e-STORAGE conducted the cycle life test at 25 °C and 45 °C at 0.5P charge and discharge rates. The rest time is 30 minutes for the 25 °C test and 10 minutes for the 45 °C test. Figure 3-4 shows degradation curves of e-STORAGE's 314 Ah cell.

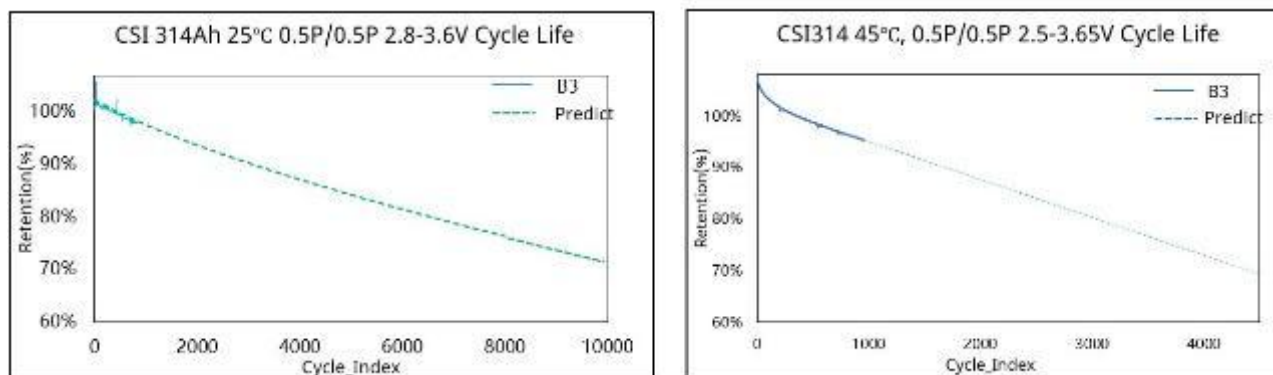


Figure B-4 Degradation curves of e-STORAGE's 314 Ah cell at 25 °C and 45 °C

The degradation curves, which is obtained by simulation following the actual experimental data, indicate that the expected energy retention of e-STORAGE's 314 Ah cell at 25 °C and 45 °C are 71% after 10,000 cycles and 70% after 4,500 cycles, respectively. DNV notes that these expectations are reasonable and in-line with similar cell products in the market.

DNV is unable to comment on the reliability of the prediction, which require verification periodically when more actual data becomes available.

DNV notes that the claim of cycle performance in the product technical specification is for users' reference only. In the real application, the degradation can vary depending on many factors such as C-rates, ambient temperature, average SOC, depth of discharge (DoD), SOC swing, etc.

B.3.3.2 Calander degradation and storage

e-STORAGE conducted storage tests of the cell for 30 days under two conditions – 1) 45 °C at 25% SOC, and 2) 25 °C at 25% SOC, see Figure B-5. The major indicators of the storage test are residual energy, which is the remaining cell capacity after storage, and energy recovery, which is defined by the ratio of charge/discharge capacity after storage to that of before storage.



Figure B-5 Storage and recovery test results of e-STORAGE's 314 Ah cell

For the minimum loss due to the storage, DNV recommends cell users putting cells in storage under recommended temperature and SOC as per product technical specification document, as well as recharging the cell at the recommended interval.

Figure B-6 presents the calendar degradation characteristics of the e-STORAGE 314Ah cell, illustrating the relationship between storage energy recovery (expressed as a percentage) and storage time (in years). The x-axis spans from 0 to 20 years, representing the duration of storage, while the y-axis ranges from 70% to 110%, indicating the percentage of energy recovery over time. The experimental data includes 25 °C at 100% SOC, 45 °C at 50% SOC, and 45 °C at 100% SOC. The simulated data includes 25 °C at 50% SOC (yellow dashed line), 25 °C at 100% SOC (blue dashed line), and 45 °C at 50%

SOC (orange dashed line). Across all conditions, the graph reveals a consistent trend of declining energy capacity over time. The rate of degradation and the initial recovery levels vary depending on the temperature and SOC, underscoring the significant influence of these factors on the long-term performance and reliability of the battery cell.

DNV considers e-STORAGE 314 Ah calendar fade to be in line with industry expectations of similar products.

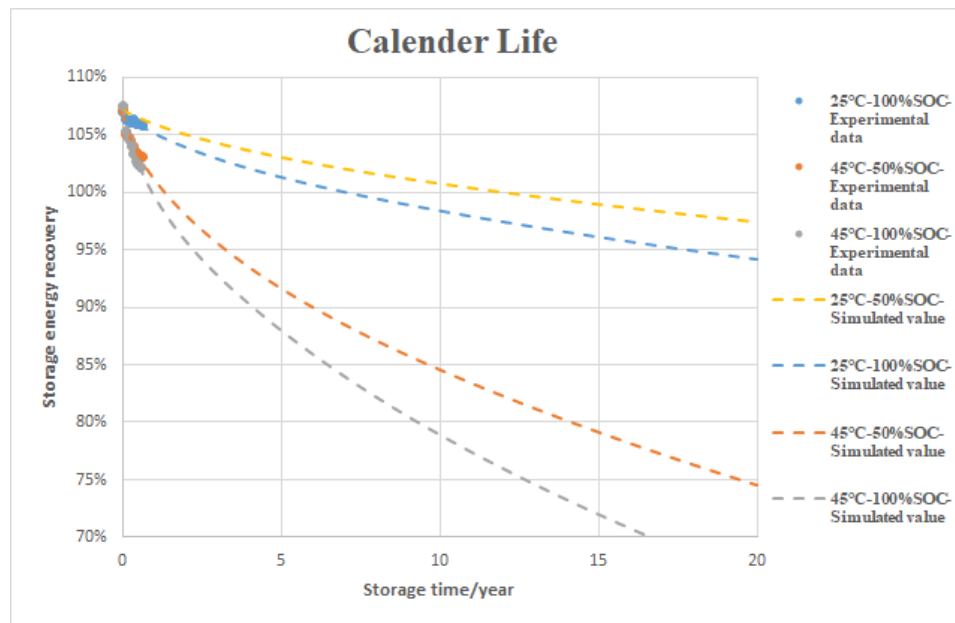


Figure B-6 Calendar fade results of e-STORAGE 314 Ah cell at various SOC% and temperatures

B.4 List of IEC test reports and certificates

Table B-4 IEC test reports and certificates list (e-STORAGE cell)

Component	Test standard	Certification/Test verified
Unit	IEC 62619	The unit model # CSI-SolBank-R-418-2h-A and CSI-SolBank-R-418-4h-A have obtained IEC 62619 certificate issued by TUV Rheinland [164] [165]
Unit	IEC 63056	The unit model # CSI-SolBank-R-418-2h-A and CSI-SolBank-R-418-4h-A have obtained IEC 63056 certificate issued by TUV Rheinland [164] [165]
Integrated BESS	IEC 62477	The BESS model # CSI-SolBank-S-5016-2h-EU and CSI-SolBank-S-5016-4h-EU (e-STORAGE cell) have obtained IEC 62477 certificate issued by TUV Rheinland [166] [167]
Integrated BESS	Low Voltage Directive (EU) 2014/35	The BESS model # CSI-SolBank-S-5016-2h-EU and CSI-SolBank-S-5016-4h-EU (e-STORAGE cell) have obtained Low Voltage Directive (EU) 2014/35 certificate of Conformity issued by TUV Rheinland [168]
Integrated BESS	IEC 61000	The BESS model # CSI-SolBank-S-5016-2h has obtained EN IEC 61000-6-2:2019, EN IEC 61000-6-4:2019 certificate by TUV SUD [169] [170]
Integrated BESS	Directive 2014/30/EU Electromagnetic Compatibility	The BESS model # CSI-SolBank-S-5016-2h-EU and CSI-SolBank-S-5016-4h-EU (e-STORAGE cell) have obtained Directive 2014/30/EU Electromagnetic Compatibility certificate by TUV Rheinland [171]
Cell	IEC 62619	The cell model # MB31 has obtained CB test certificate issued by TUV Rheinland [172]
Integrated BESS	UN 38.3	The unit model #CSI-SolBank-S-5016-2h-NA and CSI-SolBank-S-5016-4h-NA have been tested with UN38.3 requirements and test report issued by CVC Testing Technology Co., Ltd [173] [174]

B.5 UL 9540A testing

DNV has received 4th edition testing of the cell, module, and unit level for SolBank 3.0.

B.5.1 Cell-level results

DNV has reviewed the 4th edition of the UL 9540A cell level test report [62] bearing model number CSI314. At the cell level, UL 9540A tests whether thermal runaway can occur in a single cell and provides insights into onset temperatures for venting and thermal runaway as well as off-gas composition and volume. To provide comparison and benchmarks, DNV has reviewed test reports for cells that were conducted under the same or similar conditions for cells with similar chemistry, capacity and form factor.

Test method and deviations: DNV notes that the cell venting and thermal runaway temperatures reported were not recorded from under the heater as required by section 7.3.1.7 of UL 9540A 4th edition test methodology. This will likely cause the reported temperatures to be lower than what has been reported for similar cells in the industry.

Venting and thermal runaway temperatures: The cell venting temperature and thermal runaway temperature were 167.4 °C and 238.5 °C, respectively. DNV notes that the cell venting and thermal runaway temperature are average temperature that DNV has typically seen for LFP battery chemistry. The cells displayed a difference of roughly 71 °C between the temperature at cell venting and thermal runaway. DNV views the wide cell venting and thermal runaway temperature difference as beneficial for the cell as there is more of an inherent barrier in place for increasing temperatures and may provide enough time for safety systems to detect and respond to thermal events. Additionally, DNV reviewed the BMS

setting which is configured in such a way that if cell temperature exceeds 55 °C, the charging/discharging is prohibited and if cell temperature exceeds 58 °C, the BMS will disconnect the contactor within the BESS. Hence the battery will be isolated well before the cell venting temperature [88].

Gas composition and volumes: In comparison with other tests DNV has reviewed that were conducted under the same or similar conditions, the gas composition reported for the CSI cell has a slightly higher proportion of H₂. In general, however, the amount of hydrogen produced could qualitatively relate to an energetic explosion, although a detailed quantitative analysis of this data would be necessary to determine the impact. A total of 180.7L of gas was produced during the test. The volume of gas produced was lower on a per-Amp-hour basis. This may be a product of the form factor of the cell but would contribute favorably to the safety of the cell. Additionally, the BESS is equipped with gas detection systems, enhancing safety by identifying off-gassing and enabling early detection, which helps mitigate cell thermal events before they escalate to thermal runaway.

Performance criteria: DNV notes that the UL 9540A test method stipulates that the cell level test should meet the following two performance criteria: thermal runaway should not be induced, and off-gassing event should not produce flammable gases. Since flammable gases were produced which is typical for LFP cell chemistry, the cell level test did not meet the performance criteria. This is expected of cells using lithium-ion chemistry.

B.5.2 Module-level results

DNV has reviewed the 4th edition of the UL 9540A module level test report [63] bearing model number CSI-SolBank-P-104.5-2h-A, CSI-SolBank-P-104.5-4h-A. The module level test provides insights into how thermal runaway propagates from a single failed cell to adjacent cells in a module. The test results help designers optimize module design and validate safety systems in the BESS.

Test method and deviations: DNV did not identify deviations from the test method described in UL 9540A 4th edition, section 8.

Observation: The test results indicated that no fire, flames, flying debris, explosive discharge, sparks, electrical arcs or re-ignitions observed. During the test, 3 initiating cells went under thermal runaway and propagation occurred to 2 additional adjacent cells. However, Figure B-7 indicates that one cell was placed under heaters on both larger surface sides of the cell. Therefore, it will be interpreted as one cell was initiated with two heaters and cell-to-cell propagation occurred to four additional adjacent cells.



Figure B-7 Initiating cell and heaters location in battery module

In addition, the test report stated that 236.51L of hydrogen, 103.79L of carbon monoxide, 445.65L of carbon dioxide and 406.43L of hydrocarbons gases were generated during the test. Hydrogen and hydrocarbons, such as methane and propane, are explosive and flammable gases. In addition, carbon monoxide is an extremely flammable gas that can readily form an explosive mixture with air. Carbon dioxide is also an asphyxiant.

Performance criteria: DNV notes that the UL 9540A test method stipulates that the module level test should meet the following two performance criteria: thermal runaway should be contained within module, and off-gassing event should not produce flammable gases. Since flammable gases were produced in cell level testing, the module level test did not meet the performance criteria. Hence DNV recommends that the battery modules utilizing this cell, shall be subjected to UL 9540A unit level test.

B.5.3 Unit-level results

CSI has tested their BESS Unit, bearing model number CSI-SolBank-R-418-2h-A, CSI-SolBank-R-418-4h-A, to the 4th edition of the UL 9540A test methodology. TUV Rheinland conducted the unit level test [64]. UL 9540A unit tests provide insight into thermal runaway propagation beyond the single module to affect an entire unit.

BESS unit description: UL 9540A article 9.1.2 specifies that the unit level test requires initiating an internal fire (per the module level test procedure) in one BESS unit to assess fire propagation to adjacent, representatively installed BESS units. For the purposes of the test, a Unit was considered as open rack configuration which includes 4 battery modules and 1 control unit. Figure B-8 displays the location of the initiating module during unit level testing.

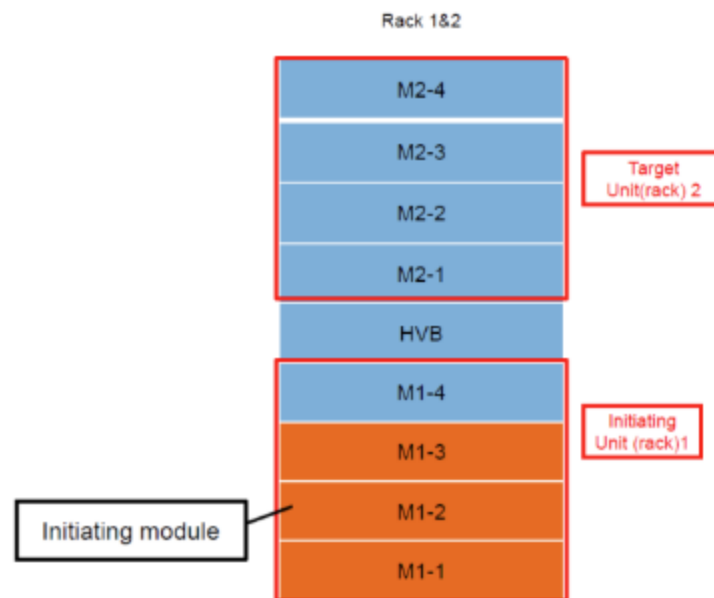


Figure B-8 Initiating module location in unit level testing

Test method and deviations: In the Unit level test, a complete BESS Unit is installed and surrounded by target (dummy) BESS and walls at the distance intended in its installation. Thermal runaway is induced in battery cells of one of the modules in the initiating BESS unit. The results are intended to report whether a fire or thermal runaway will propagate between modules and other Units, and whether there will be flying debris or explosive discharge of gas. The 4th edition UL 9540A unit-level methodology outlines procedures for different types of installation including indoor and outdoor ground mounted systems. The test report indicates this unit has been tested for non-residential indoor floor mounted use. The text of UL

9540A allows the BESS to be tested with its integral fire protection system provided by the manufacturer in the test set up. However, no fire protection system was utilized during the test.

The following provides an overview of the test set up:

- Three instrumented walls (at least 0.61 m taller than unit height and 0.49 m extended up to exterior target unit) were constructed to form a perimeter around three sides of the initiating and target units. The walls were constructed covered with 16 mm gypsum wall board and painted flat black.
- 4 Units/racks were used for this test (see Figure B-9 for arrangement).
- The minimum separation distance from the unit to wall and between units is displayed in Figure B-9. Customer indicated that the separation distance between the initiating unit and target unit is 601 mm [161].

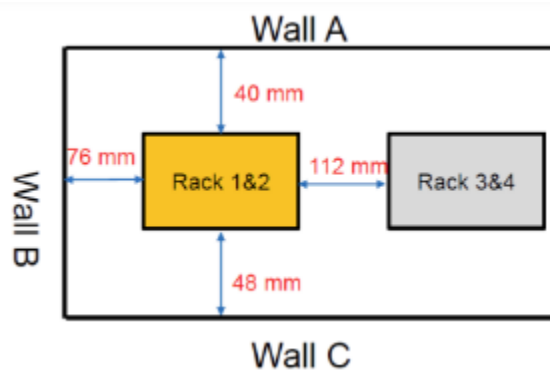


Figure B-9 Unit level test setup

Observations and performance criteria: During the tests, no flaming explosive hazards, including deflagration or detonation, were observed. Furthermore, during the test no flying debris, sparking, electrical arcs, or other electrical events occurred or were observed. The test report states that three initiating cells went under thermal runaway and cell-to-cell thermal runaway propagation occurred to additional two adjacent cells. However, Figure B-10 indicates that one cell was placed under heaters on both larger surface sides of the cell. Therefore, it should be interpreted as one cell was initiated with two heaters and cell-to-cell propagation occurred to four additional adjacent cells.

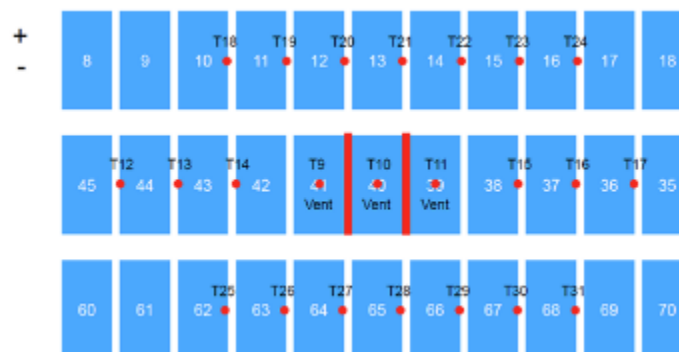


Figure B-10 Initiating cell and heaters location in battery module

As stated in the test report, 262.54 L of hydrogen, 113.02 L of carbon monoxide, 482.91 L of carbon dioxide and 449.50 L of hydrocarbons gases were produced. Table B-5 provides an overview of the performance conditions set forth by UL 9540A in addition to the summary of the Unit test observations.

Table B-5 UL 9540A Unit performance criteria for indoor floor mounted BESS

Performance condition	Test observation/remark
Flaming outside the initiating BESS unit is not observed	Meets the performance criteria. No flaming was observed internally or externally of the Unit during the test.
Surface temperatures of modules within the target units adjacent to the initiating unit do not exceed the temperature at which thermally initiated cell venting occurs, as determined in 7.3.1.8.	Meets the performance criteria. The maximum surface temperature measured on target Unit was 21.3 °C, far below the cell venting temperature of 167.4 °C reported in the cell-level test.
For units intended for installation in locations with combustible constructions, surface temperature measurements on wall surfaces do not exceed 97 °C of temperature rise above ambient temperature per 9.2.15.	Meets the performance criteria. The maximum surface temperature on the adjacent walls was 70.7 °C, below the 97 °C temperature rise performance criteria.
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.	Meets the performance criteria. Explosion hazards were not observed during the test (internal and external).
Heat flux in the center of the accessible means of egress shall not exceed 1.3 kW/m ²	Meets the performance criteria. Maximum ~0.35 kW/m ² heat flux detected on instrument wall.

While cell-to-cell propagation occurred during the test, module-to-module and unit-to-unit propagation was not observed indicating an adequate thermal barrier between modules. The Unit level results show a resiliency of the Unit to thermal runaway propagation and fire hazard in a single failure event. The unit level performance criteria have been met, therefore, the tested spacing distances can be used as the minimum spacing for the BESS installation.

B.6 Explosion prevention

Methodology: The explosion/deflagration prevention system is designed to reduce the concentration of flammable gas inside the BESS enclosure below 25% LFL by means of a ventilation system. Systems that employ this methodology are required to comply with NFPA 69 design guidelines (Standard on Explosion Prevention Systems).

System description: Although the enclosure dimensions result in a total volume of 31.38 m³, subtracting out the internal components of the cabinet results in an open volume for air of 8.74 m³. The ventilation system is comprised of 2 hydrogen gas sensors and a ventilation system which includes 1 exhaust fan and 2 motorized louver intakes as displayed in **Figure 5-16**. The exhaust fan is manufactured by Nanjing Heben M&E Equipment Technology Co., Model #: TPF13, TPF14; size: 410x360 mm with a rated ideal air flow capacity of 1390 m³/h (820 CFM). The report states that due to the flow restriction of the components inside the container the fan operates at 1020 m³/h (600 CFM). The 1020 m³/h flow rate was the flow rate used to run the CFD calculations. DNV finds the noted reduction in flow from ideal to actual to meet expectations.

When a Level-1 gas detection alarm (concentration above 10% LEL) occurs the ventilation system opens the intake louvers and operates the exhaust fan to purge the battery cabinet with ventilation.

Design compliance: Systems that employ methodology described above are required to comply with NFPA 69 design guidelines (Standard on Explosion Prevention Systems). DNV reviewed a CFD (Computational Fluid Dynamics) analysis report [175] which demonstrates the deflagration prevention system's performance using NFPA 69 guidelines through a set of documented technical assumptions.

The CFD simulation was accompanied by the UL 9540A 4th edition cell, module and unit level test results of SolBank 3.0 associated with CSI cell model # CSI314 which includes the flammable gas concentration, number of cell's failure and gas release rate. Based on UL 9540A test results, a total 5 cell's failure scenario resulting in a total of 132.8 LPM gas release rate was assumed in the CFD simulation. The gas release rate kept constant throughout the simulation as a conservative approach. DNV views the flow modeling decisions to follow reasonable engineering judgement.

Furthermore, 3 gas release positions are identified as at the bottom module of the left rack, middle rack, and right rack of the enclosure. DNV finds the assumptions regarding the gas release positions to be effective for the conservative analysis, as the detection location was furthest from the gas release location which introduced delay in detecting. Additionally, this setup is helpful in evaluating the performance of the fan in removing flammable gases from the bottom surfaces.

DNV notes these technical assumptions, gas release location, gas release rate and reduced air flow rate are reasonably go above and beyond the scenario described in UL 9540A testing, and views them favorably.

The simulation results indicate that the ventilation system can maintain the flammable gas concentration below 25% of LFL for all 3 scenarios. While small pockets, higher than 25% of LFL, were observed during these simulations, which DNV views as typical scenario for BESS. Based on the technical assumptions, the CFD analysis report concludes that the ventilation system is designed in accordance with NFPA 69 requirements, DNV takes no exception to these conclusions.

B.7 Explosion protection

Methodology: Explosion protection for this BESS is achieved through deflagration venting as described in NFPA 68:2023, Chapter 6. In simple terms, if flammable gases released during a battery thermal runaway event ignite inside the sealed container, lightweight vent panels (rupture diaphragms) mounted on the enclosure walls burst open at a preset pressure (0.1 bar-g), allowing the expanding combustion gases and pressure to escape outward before the internal pressure exceeds the structural capacity of the container. The design objective is to ensure that the reduced explosion pressure inside the enclosure (Pred) remains below a safe fraction of the container's ultimate structural strength, thereby preventing catastrophic failure.

System Description: The BESS. The system under evaluation is the CSI SolBank S-5016 series, a containerized DC battery energy storage system housed in a standard 20-foot equivalent enclosure measuring 6,058 × 2,438 × 2,896 mm. The gross internal volume of the battery cabinet is approximately 31.38 m³, with an effective (open) internal volume of 8.74 m³ after subtracting the space occupied by racks, modules, and structural supports. The choice of five roof-mounted vent panels on a container of this size is a reasonable design approach, and their placement on the roof is well-considered.

Five deflagration vent panels manufactured by BasCo (model EPS-CP-610×610) are installed on the container roof. Each panel provides an effective vent area of 0.610 × 0.610 m (0.372 m²), yielding a total vent area of approximately 1.861 m². The panels are rupture diaphragm-type devices that activate at a static opening pressure (Pstat) of 0.1 bar-g.

Technical Assumptions: Several conservative assumptions build meaningful engineering margin. Using the highest gas mass among the three test levels (700.90 g from the cell-level calculation, which exceeds the unit-level value by ~2%) is appropriately conservative. Disabling the ventilation system during the deflagration scenario (Assumption 5) ensures the analysis captures the worst-case gas concentration at the time of ignition.

The selection of three ignition positions, center, front center, and front corner represents a reasonable bounding approach, and the finding that the top-center ignition produces the highest pressure is consistent with the expected gas distribution pattern (hydrogen accumulating at the ceiling).

The difference between the worst-case Pred (0.350 bar-g) and the allowable limit (0.367 bar-g) is only 0.017 bar-g, representing a margin of approximately 4.6%. Secondly, the enclosure's mechanical strength of 0.55 bar-g is client-provided and not independently verified by TUV in this report. The report explicitly states that CSI is responsible for the enclosure's mechanical strength. This means the central compliance conclusion that $Pred < 2/3 \times \text{ultimate strength}$ rests on a self-reported enclosure capacity that has not been independently validated within this analysis. If the actual enclosure strength were even marginally lower (e.g., 0.50 bar-g due to construction tolerances, weld quality, or corrosion), the allowable Pred would drop to 0.333 bar-g, and the worst-case scenario would exceed the limit.

Compliance: The overall compliance conclusion per the report is that the design meets NFPA 68:2023 Chapter 6 requirements, though the tight structural margin of 4.6% and the absence of independent enclosure strength verification represent areas where additional substantiation would be beneficial

APPENDIX C – EVE

DNV leveraged a prior technology review report of EVE's 314 Ah cell for this section [176].

C.1 Company Evaluation

EVE, a battery manufacturer, initially specialized in consumer batteries before expanding into electric vehicle (EV) and energy storage batteries. The company has a long-standing history of producing various battery types, including small flexible battery packs, bean-count batteries, 21700 cylindrical batteries, 46 series large cylindrical batteries, and 280 Ah and 314 Ah prismatic batteries. EVE employs 27,339 people.

EVE has developed a wide range of energy storage products. For battery cells, EVE offers 50 Ah cylindrical cells for residential energy storage systems (ESS) and portable energy storage. For energy storage cabinets and containers, it offers 280 Ah prismatic cells, 300 Ah prismatic cells, and 314 Ah prismatic cells. Additionally, EVE provides liquid-cooled energy storage system solutions, which include liquid-cooled battery modules, energy storage cabinets, and containerized energy storage systems.



Figure C-1 EVE Energy Co., Ltd. Development Milestones

C.1.1 Intellectual Property

As of July 2024, EVE holds nearly 6,000 active patents. DNV notes that over 5,600 of these patents are filed in China, 9 in the United States, 12 in Japan and Korea, 9 in Europe, and 237 with the World Intellectual Property Organization. DNV has not reviewed any of these patents in detail.

C.1.2 Financial Status

EVE has demonstrated significant financial growth over the years, see Figure C-2 for details.

In 2021, the company reported:

- Revenue: \$2.62 billion (CNY 16.9 billion)
- Net Profit: \$451 million (CNY 2.906 billion)
- R&D Expenses: \$203 million (CNY 1.31 billion)

In 2023, the company reported:

- Revenue: \$6.90 billion (CNY 48.784 billion)
- Net Profit: \$573 million (CNY 4.05 billion)
- R&D Expenses: \$387 million (CNY 2.731 billion)

The compound annual growth rate (CAGR) for revenue from 2021 to 2023 is approximately 61.6%. Power battery revenue accounted for nearly 50% of the total revenue, while energy storage battery revenue accounted for more than 30%.

The increase in revenue and net profit over these years shows the company's growth.

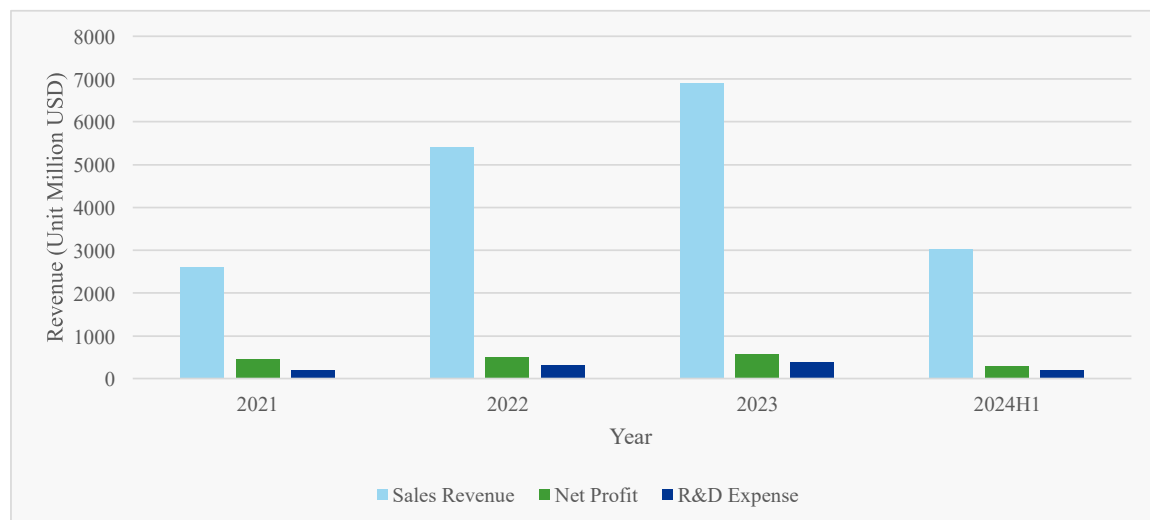


Figure C-2 Financial status of EVE between 2021 to 2023

C.2 Battery cell specifications

Figure C-3 presents prismatic EVE's 314 Ah LFP cell. The cell specifications are presented in Table C-1, which includes several parameters such as capacity, operating voltage and operating temperature conditions [145].



Figure C-3 EVE's 314 Ah LFP cell

Table C-1 EVE 314 battery cell specifications

Parameter	Specification
Cell type / chemistry	Type: Prismatic Chemistry: LFP
Cell model	MB31
Nominal capacity	314 Ah
Operating voltage range	2.5 V to 3.65 V ($T > 0^{\circ}\text{C}$) 2.0 V to 3.65 V ($T \leq 0^{\circ}\text{C}$)
Nominal voltage	3.2 V
Nominal energy	1004.8 Wh
AC-impedance	$0.18 \pm 0.05 \text{ m}\Omega$
Maximum charge/discharge current	502.4 W (0.5P)
Discharge end voltage	2.5 A
Maximum operating temperature range (Charge)	0°C to 60°C

Parameter	Specification
Maximum operating temperature range (Discharge)	-30 °C to 60 °C
Optimal operating temperature range (Charge)	25 ± 2 °C
Optimal operating temperature range (Discharge)	25 ± 2 °C
Storage temperature (12 months)	0 °C to 35 °C
Cell dimensions (W x L x H)	71.7±0.8mm × 173.7±0.5mm × 207.2±0.5mm
Weight	5.60 ± 0.30 kg
Energy density	179.43 Wh/kg

DNV notes that the charge temperature's lower limit is set above 0 °C, ensuring that the cells are not charged in freezing conditions. The upper limit, on the other hand, is higher than most, typically not exceeding 55 °C. Additionally, the maximum operating temperature range for discharge is lower than -30 °C for the e-STORAGE 314 cell. EVE's 314 Ah cell impedance is also lower than that of Hithium and e-STORAGE cells.

Overall, DNV considers EVE 314 Ah cell specifications to be in line with similar products in industry.

DNV requested clarification regarding the storage temperature window (0 °C to 35 °C) of the EVE cell, which is narrower than the BESS system's specified storage range of -20 °C to 45 °C and recommends updating it once the information is available.

C.3 Performance evaluation

C.3.1 Capacity

The cell capacity test conducted by EVE was performed at a temperature of 25 °C. During the test, the cell was charged using a constant power of 0.5P (502.4 W) until it reached a voltage of 3.65 V. Following the charging phase, the cell was discharged down to a voltage of 2.5 V. Additionally, there was a 10-minute rest period between each charge and discharge cycle. Capacity results are shown in Table 3-2.

Table C-2 Capacity results of EVE's 314 Ah cell

No.	Charge capacity (Ah)	Discharge capacity (Ah)	Charge energy (Wh)	Discharge energy (Wh)	Energy efficiency
1	325.525	325.965	1096.78763	1041.98172	95.00%
2	325.695	326.191	1097.15271	1043.06644	95.07%
3	326.029	326.574	1098.61499	1044.03493	95.03%
4	324.698	325.338	1095.13804	1039.01447	94.88%
5	324.026	324.693	1093.46706	1036.61868	94.80%

Figure C-4 shows charge and discharge curves of EVE 314 Ah cell. The cell displays typical plateaus around 3.1 V to 3.4 V. Notably, the cell's discharge capacity exceeds its rated capacity at 25 °C. DNV has positively evaluated these capacity results, confirming that they meet the design criteria.

The cell exhibits typical charge and discharge plateaus around 3.1 V to 3.4 V, which signals minimal electrochemical side reactions occurring during charging and discharging. The discharge capacity of the cell exceeds the rated capacity under 25 °C. DNV notes that the discharge capacity is not typically higher than the charge capacity. EVE shall clarify these results further.

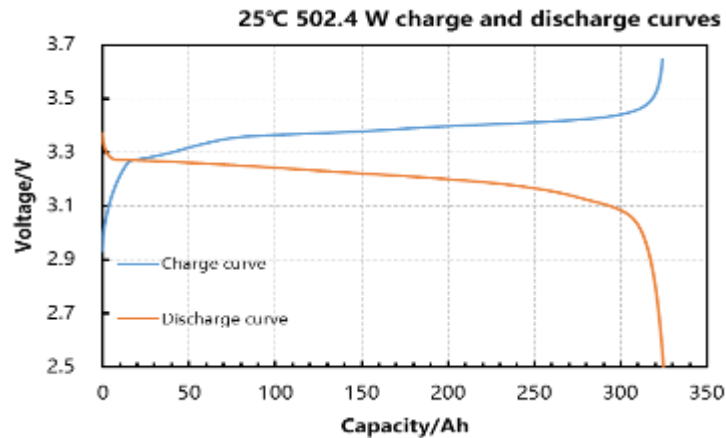


Figure C-4 Charge and discharge curves of EVE's 314 Ah cell

C.3.2 Power capability and duration

Rate capability in batteries refers to their ability to charge and discharge at different rates without significant performance loss. Temperature significantly impacts this, as higher temperatures typically enhance power capabilities by lowering internal resistance. C-rate indicates the speed at which a cell is charged from 0% SOC to 100% SOC or discharged from 100% SOC to 0% SOC. For example, a 0.5C discharge rate means it takes two hours to fully charge the cell from a fully discharged state. DNV notes that using a cell at a high C-rate can have adverse effects over time and high C-rate can cause particle cracking in the electrode material, leading to rapid degradation.

For cells designed for ESS applications, cell manufacturers more commonly characterize the cells by using constant power rate (P-rate).

EVE's 314 Ah cell is tested under 0.25P, 0.5P, and 1.0P. The cells are charged to 3.65 V and discharged to 2.5 V, with 10 minutes rest between charge and discharge. Figure C-5 shows charge and discharge curves of EVE's 314 Ah cell at different P-rates.

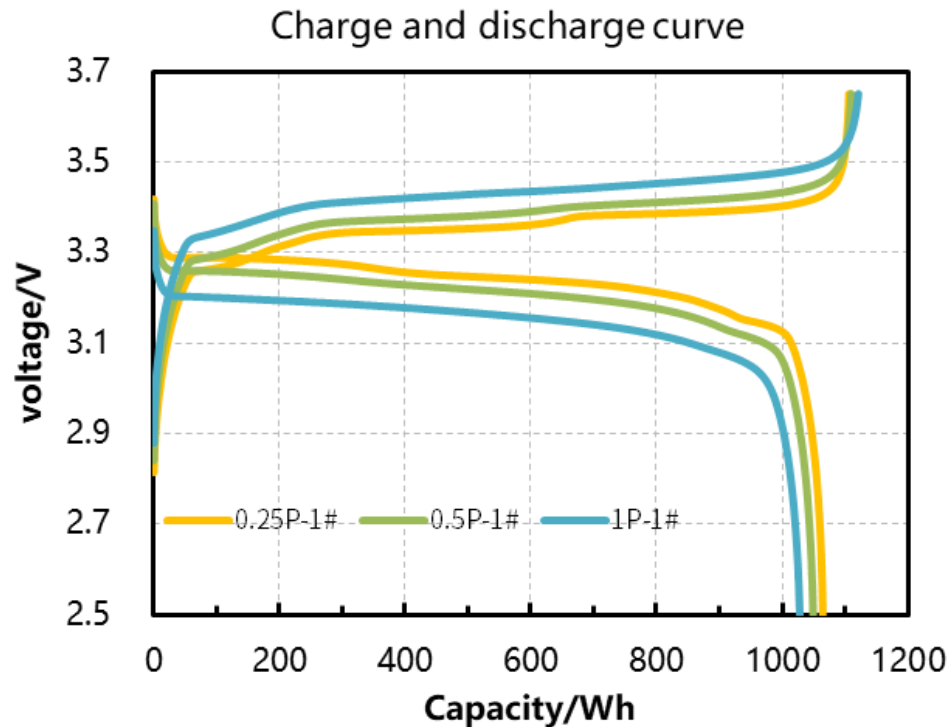


Figure C-5 Rate capability tests of EVE 314 Ah cell at 0.5P

Table C-3 C-rate test results of EVE's 314 Ah cell

C-rate	Charge capacity (Ah)	Discharge capacity (Ah)	Charge energy (Wh)	Discharge energy (Wh)	Energy efficiency	Charge temperature rise (°C) ¹	Discharge temperature rise (°C)
0.25P	330.59	330.29	1106.22	1064.66	96.24%	2.7	3.5
0.5P	328.95	328.72	1109.95	1049.37	94.54%	5.8	7.2
1.0P	327.80	327.41	1121.22	1028.04	91.69%	14.4	15.8

EVE tested the cell under various temperatures across 45 °C to -20 °C. Figure C-6 shows discharge curves of EVE's 314 Ah cell at different temperatures. Changes in the rate influence the voltage plateaus and delivered capacity. Higher rates (e.g., 1.5P and 2P) can lead to increased internal resistance and heat generation, which may cause the voltage plateaus to shift and reduce the overall capacity delivered.

The discharge capacity exceeds the rated capacity when the temperature is above 10 °C, which is a typical characteristic of similar cell products in the market. Conversely, at low temperature such as 0 °C, -10 °C, and -20 °C, the discharge capacities of the cell are lower than that at 25 °C, which is expected (see Figure C-6).

DNV notes that typically the optimal temperature range for a Li-ion cell is between 15 °C to 30 °C. It is critical to maintain the cell operating temperature by deploying a thermal management system in large scale ESS applications.

The test procedure involved charging the cells to 3.65 V and discharging them to 2.5 V, with a 10-minute rest period between each charge and discharge cycle. DNV notes that the discharge capacity at -20 °C and -10 °C meet the rated capacity and exceed the discharge capacity at 0 °C. This is due to the use of 2.0 V as the discharge cut-off voltage provides wider operating voltage window.

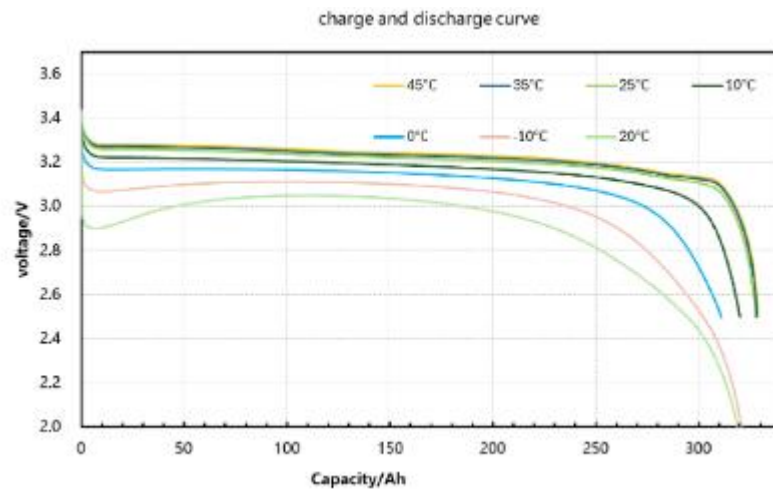


Figure C-6 Discharge profiles of 314 Ah at various temperatures

Table C-4 Temperature performance of EVE's 314 Ah cell

Temperature (°C)	Charge capacity (Ah)	Discharge capacity (Ah)	Charge energy (Wh)	Discharge energy (Wh)
-20	326.85	318.88	1099.83	922.63
-10	327.26	320.85	1101.37	957.64
0	327.52	311.09	1102.46	964.22
10	327.61	320.0	1103.03	1008.81
25	328.02	327.45	1104.43	1045.66
35	328.27	328.13	1105.57	1052.28
45	328.54	328.50	1107.05	1056.13

DNV requested EVE cell charge capacity tests at different temperatures, however this data was not available. DNV will update this information once it is available.

C.3.3 Degradation

C.3.3.1 Cycle life and capacity retention

Cycle life performance, or degradation, is a measure of cell's product life under certain operating conditions. The indicator of the cycle life performance is the capacity retention, which is calculated as the ratio of discharge capacity of any cycle to the initial discharge capacity at the fresh state. This measure is often known as the state of health.

EVE conducted the cycle life test at 25 °C with 0.5P charge and discharge rates. The rest time between charge and discharge is one hour. The cell degradation curve includes the simulation curve illustrated in dash lines [4]. The test data indicates that EVE's 314 Ah cell delivers discharge capacity of 307.32 Ah after 947 cycles, which corresponds to the SOH of 93.43%. The degradation curve, which is drawn by a simulation tool developed by EVE, indicates that the expected energy retention of EVE's 314 Ah cell is approximately 60% after 9,000 cycles at 25 °C. DNV notes that the capacity retention of the 314 Ah cell is expected to reach approximately 75% after 8,000 cycles. DNV is unable to opine on the reliability of this prediction, which requires verification periodically when further cycling data becomes available.

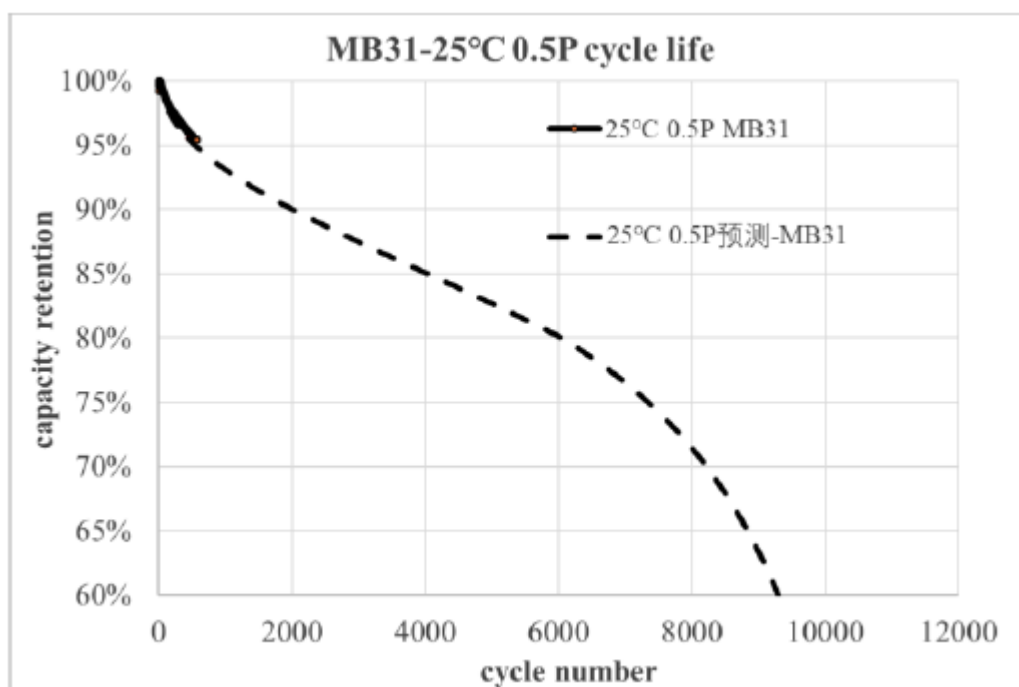


Figure C-7 Expected degradation curve of EVE's 314 Ah cell

DNV requested cycling degradation such as C-rates, ambient temperature, average SOC, depth of discharge (DoD), SOC swing, etc and recommends updating it once the information is available.

C.3.3.2 Calendar degradation and storage

Calendaric degradation refers to the loss of battery capacity and efficiency over time, regardless of cycling activity, primarily due to chemical changes within the cell during storage. The degree of calendaric degradation is significantly influenced by the SOC at which the battery is stored and the ambient temperature. The test results illustrate the impact of SOC and temperature on battery performance, with higher SOC and temperatures leading to more rapid capacity loss over time.

EVE conducted the storage tests of the cell under two conditions – 1) 25 °C at 100% SOC, and 2) 45 °C at 100% SOC, see Figure C-8 and Table C-5. The major indicators of the storage test are energy residual, which is the remaining cell capacity after storage, and energy recovery, which is defined by the ratio of charge/discharge capacity after storage to that before storage.

EVE has collected the monthly capacity recovery ratio over a period of 11 months. DNV notes a significant drop in the capacity recovery ratio for the high-temperature test at 45 °C and 100% SOC. This decline is typical at higher temperatures and higher SOC levels.

DNV requested calendar fade results up to 12 months. DNV will update this information once available.

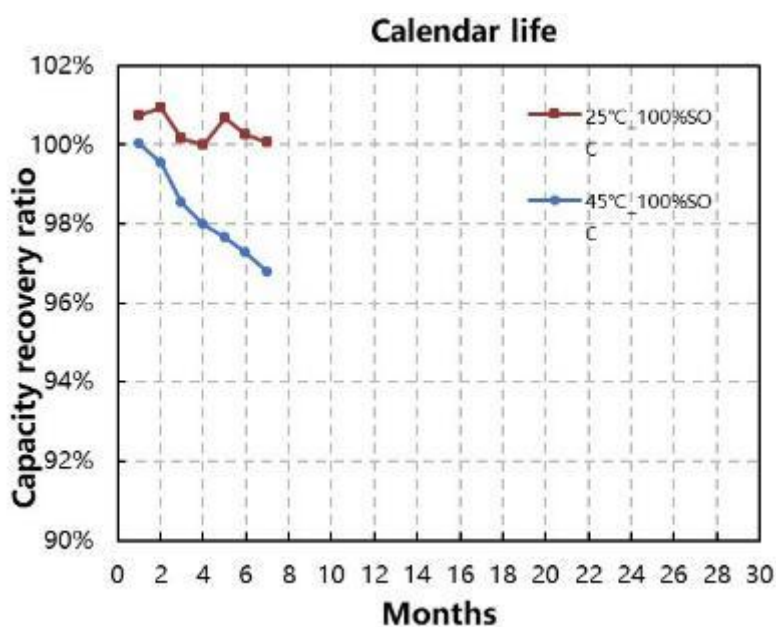


Figure C-8 Calendar fade of EVE's 314 Ah cell

Table C-5 Capacity recovery rate of EVE's 314 Ah cell under different storage conditions

Parameter	1 st month	2 nd month	3 rd month	4 th month	5 th month	6 th month	7 th month	8 th month	9 th month	10 th month	11 th month
25 °C@100% SOC	100.75%	100.93%	100.16%	99.99%	100.67%	100.25%	100.04%	99.89%	99.78%	99.71%	99.44%
45 °C@100% SOC	100.03%	99.55%	98.53%	97.98%	97.64%	97.26%	96.80%	96.42%	95.76%	95.28%	94.95%

The storage and recovery performance of EVE's 314 Ah is aligned with typical performance of similar cell products in the market. For the minimum loss due to the storage, it is crucial for cell users to put cells in storage under recommended temperature and SOC as per product technical specification document, as well as recharging the cell at the recommended interval.

Table C-6 IEC test reports and certificates list (EVE cell)

Component	Test standard	Certification/Test verified
Unit	IEC 62619	The unit model # CSI-SolBank-R-418-2h-E and CSI-SolBank-R-418-4h-E have obtained IEC 62619 certificate issued by TUV Rheinland [177] [178]
Unit	IEC 63056	The unit model # CSI-SolBank-R-418-2h-E and CSI-SolBank-R-418-4h-E have obtained IEC 63056 certificate issued by TUV Rheinland [177] [178]
Integrated BESS	IEC 62477	The BESS model # CSI-SolBank-S-5016-2h-EU and CSI-SolBank-S-5016-4h-EU (EVE cell) have obtained IEC 62477 certificate issued by TUV Rheinland [179] [180]
Integrated BESS	Low Voltage Directive (EU) 2014/35	The BESS model # CSI-SolBank-S-5016-2h-EU and CSI-SolBank-S-5016-4h-EU (EVE cell) have obtained Low Voltage Directive (EU) 2014/35 certificate of Conformity issued by TUV Rheinland [181]
Integrated BESS	IEC 61000	The BESS model # CSI-SolBank-S-5016-2h-EU and CSI-SolBank-S-5016-4h-EU (EVE cell) has obtained certificate of conformity for EN IEC 61000-6-4:2019, IEC 61000-6-4:2018, EN IEC 61000-6-2:2019, IEC 61000-6-2:2016 by TUV Rheinland [182]
Cell	IEC 62619	The cell model # MB31 has obtained CB test certificate issued by TUV Rheinland [172]
Integrated BESS	UN 38.3	The unit model #CSI-SolBank-S-5016-2h-NA and CSI-SolBank-S-5016-4h-NA have been tested with UN38.3 requirements and test report issued by CVC Testing Technology Co., Ltd [183] [184]

C.4 UL 9540A testing

UL 9540A testing is a destructive test method used for evaluating the thermal runaway impacts in a BESS and gathering data to assist in assessing or developing mitigation measures for the failure event, propagation of the failure, or consequences of an event, such as an explosion or fire. The test, which does not have pass/fail criteria, can be performed on a cell, module, or unit level. UL 9540A is ANSI (American National Standards Institute) accredited and is currently considered to be the most appropriate published methodology to provide comprehensive, consistent, and reliable third-party data for battery failure testing. DNV notes that UL 9540A is a requirement for the UL 9540 certification mandated by code in Section 1207.11.1 of the 2024 IFC.

The following sections summarize the cell, module and unit level tests.

C.4.1 Cell-level results

DNV has reviewed the 4th edition of the UL 9540A cell level test report [69] bearing model number MB31. At the cell level, UL 9540A tests whether thermal runaway can occur in a single cell and provides insights into onset temperatures for venting and thermal runaway as well as off-gas composition and volume. To provide comparison and benchmarks, DNV has reviewed test reports for cells that were conducted under the same or similar conditions for cells with similar chemistry, capacity and form factor.

Test method and deviations: DNV notes that the cell venting and thermal runaway temperatures reported were not recorded from under the heater as required by section 7.3.1.7 of UL 9540A 4th edition test methodology. This will likely cause the reported temperatures to be lower than what has been reported for similar cells in the industry.

Venting and thermal runaway temperatures: The cell venting temperature and thermal runaway temperature were 154.0 °C and 225.0 °C, respectively. DNV notes that the cell venting and thermal runaway temperatures are below average temperature that DNV has typically seen for LFP battery chemistry. The cells displayed a difference of roughly 71 °C between the temperature at cell venting and thermal runaway. DNV views the wide cell venting and thermal runaway temperature difference as beneficial for the cell as there is more of an inherent barrier in place for increasing temperatures and may provide enough time for safety systems to detect and respond to thermal events. Additionally, DNV reviewed the BMS setting which is configured in such a way that if cell temperature exceeds 55 °C, the charging/discharging is prohibited and if cell temperature exceeds 58 °C, the BMS will disconnect the contactor within the BESS. Hence the battery will be isolated well before the cell venting temperature [88].

Gas composition and volumes: In comparison with other tests DNV has reviewed that were conducted under the same or similar conditions, the gas composition reported for the EVE cell has a slightly higher proportion of H₂. In general, however, the amount of hydrogen produced could qualitatively relate to an energetic explosion, although a detailed quantitative analysis of this data would be necessary to determine the impact. A total of 192.5L of gas was produced during the test. The volume of gas produced was lower on a per-Amp-hour basis. This may be a product of the form factor of the cell but would contribute favorably to the safety of the cell. Additionally, the BESS is equipped with gas detection systems, enhancing safety by identifying off-gassing and enabling early detection, which helps mitigate cell thermal events before they escalate to thermal runaway.

Performance criteria: DNV notes that the UL 9540A test method stipulates that the cell level test should meet the following two performance criteria: thermal runaway should not be induced, and off-gassing event should not produce flammable gases. Since flammable gases were produced which is typical for LFP cell chemistry, the cell level test did not meet the performance criteria. This is expected of cells using lithium-ion chemistry.

C.4.2 Module-level results

DNV has reviewed the 4th edition of the UL 9540A module level test report [70] bearing model number CSI-SolBank-P-104.5-2h-E, CSI-SolBank-P-104.5-4h-E. The module level test provides insights into how thermal runaway propagates from a single failed cell to adjacent cells in a module. The test results help designers optimize module design and validate safety systems in the BESS.

Test method and deviations: DNV did not identify deviations from the test method described in UL 9540A 4th edition, section 8.

Observation: The test results indicated that no fire, flames, flying debris, explosive discharge, sparks, electrical arcs or re-ignitions observed. During the test, two initiating cells went under thermal runaway and propagation occurred to one additional adjacent cells. However, Figure C-9 indicates that one cell was placed under heaters on both larger surface sides of the cell. Therefore, it should be interpreted as one cell was initiated with two heaters and cell-to-cell propagation occurred to two additional adjacent cells.



Figure C-9 Initiating cell and heaters location in battery module

In addition, the test report stated that 175.11 L of hydrogen, 93.62 L of carbon monoxide, 138.21 L of carbon dioxide and 184.30 L of hydrocarbons gases were generated during the test. Hydrogen and hydrocarbons, such as methane and propane, are explosive and flammable gases. In addition, carbon monoxide is an extremely flammable gas that can readily form an explosive mixture with air. Carbon dioxide is also an asphyxiant.

Performance criteria: DNV notes that the UL 9540A test method stipulates that the module level test should meet the following two performance criteria: thermal runaway should be contained within module, and off-gassing event should not produce flammable gases. Since flammable gases were produced in cell level testing, the module level test did not meet the performance criteria. Hence DNV recommends that the battery modules utilizing this cell, shall be subjected to UL 9540A unit level test.

C.4.3 Unit-level results

CSI has tested their BESS Unit, bearing model number CSI-SolBank-R-418-2h-E, CSI-SolBank-R-418-4h-E, to the 4th edition of the UL 9540A test methodology. TUV Rheinland conducted the unit level test [71]. UL 9540A unit tests provide insight into thermal runaway propagation beyond the single module to affect an entire unit.

BESS unit description: UL 9540A article 9.1.2 specifies that the unit level test requires initiating an internal fire (per the module level test procedure) in one BESS unit to assess fire propagation to adjacent, representatively installed BESS units. For the purposes of the test, a Unit was considered as open rack configuration which includes 4 battery modules and 1 control unit. Figure C-10 displays the location of the initiating module during unit level testing.

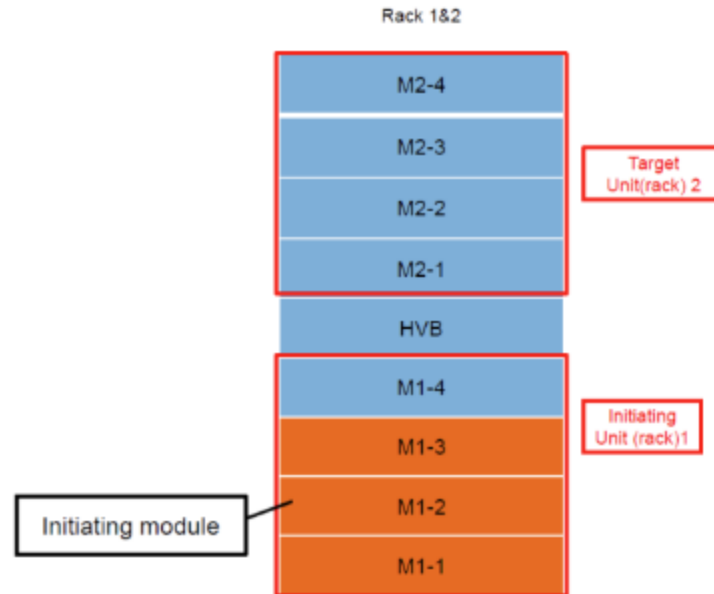


Figure C-10 Initiating module location in unit level testing

Test method and deviations: In the Unit level test, a complete BESS Unit is installed and surrounded by target (dummy) BESS and walls at the distance intended in its installation. Thermal runaway is induced in battery cells of one of the modules in the initiating BESS unit. The results are intended to report whether a fire or thermal runaway will propagate between modules and other Units, and whether there will be flying debris or explosive discharge of gas. The 4th edition UL 9540A unit-level methodology outlines procedures for different types of installation including indoor and outdoor ground mounted systems. The test report indicates this unit has been tested for non-residential indoor floor mounted use. The text of UL 9540A allows the BESS to be tested with its integral fire protection system provided by the manufacturer in the test set up. However, no fire protection system was utilized during the test.

The following provides an overview of the test set up:

- Three instrumented walls (at least 0.61 m taller than unit height and 0.49 m extended up to exterior target unit) were constructed to form a perimeter around three sides of the initiating and target units. The walls were constructed covered with 16 mm gypsum wall board and painted flat black.
- 4 Units/racks were used for this test (see Figure C-11 for arrangement).
- The minimum separation distance from the unit to wall and between units is displayed in Figure C-11. Customer indicated that the separation distance between the initiating unit and target unit is 601 mm [161].

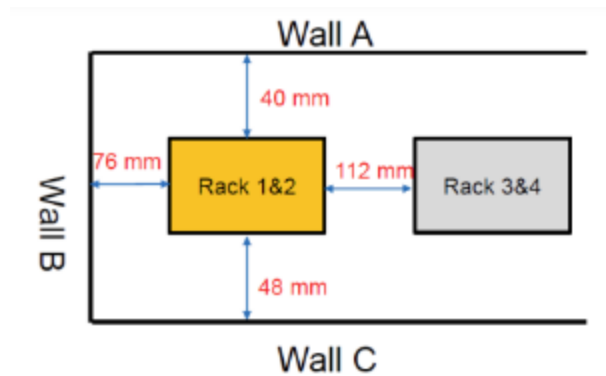


Figure C-11 Unit level test setup

Observations and performance criteria: During the tests, no flaming explosive hazards, including deflagration or detonation, were observed. Furthermore, during the test no flying debris, sparking, electrical arcs, or other electrical events occurred or were observed. The test report stated that three initiating cells went under thermal runaway and cell-to-cell thermal runaway propagation occurred to additional three adjacent cells. However, Figure C-12 indicates that one cell was placed under heaters on both larger surface sides of the cell. Therefore, it should be interpreted as one cell was initiated with two heaters and cell-to-cell propagation occurred to two additional adjacent cells



Figure C-12 Initiating cell and heaters location in battery module

As stated in the test report, 360.53 L of hydrogen, 182.18 L of carbon monoxide, 350.88 L of carbon dioxide and 379.68 L of hydrocarbons gases were produced. Table C-7 provides an overview of the performance conditions set forth by UL 9540A in addition to the summary of the Unit test observations.

Table C-7 UL 9540A Unit performance criteria for indoor floor mounted BESS

Performance condition	Test observation/remark
Flaming outside the initiating BESS unit is not observed	Meets the performance criteria. No flaming was observed internally or externally of the Unit during the test.
Surface temperatures of modules within the target units adjacent to the initiating unit do not exceed the temperature at which thermally initiated cell venting occurs, as determined in 7.3.1.8.	Meets the performance criteria. The maximum surface temperature measured on target Unit was 35.7 °C, far below the cell venting temperature of 154 °C reported in the cell-level test.
For units intended for installation in locations with combustible constructions, surface temperature measurements on wall surfaces do not exceed 97 °C of temperature rise above ambient temperature per 9.2.15.	Meets the performance criteria. The maximum surface temperature on the adjacent walls was 36.9 °C, below the 97 °C temperature rise performance criteria.
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.	Meets the performance criteria. Explosion hazards were not observed during the test (internal and external).
Heat flux in the center of the accessible means of egress shall not exceed 1.3 kW/m ²	Meets the performance criteria. Maximum ~0.85 kW/m ² heat flux detected on instrument wall.

While cell-to-cell propagation occurred during the test, module-to-module and unit-to-unit propagation was not observed indicating an adequate thermal barrier between modules. The Unit level results show a resiliency of the Unit to thermal runaway propagation and fire hazard in a single failure event. The unit level performance criteria have been met, therefore, the tested spacing distances can be used as the minimum spacing for the BESS installation.

C.5 Explosion prevention

Methodology: The explosion/deflagration prevention system is designed to reduce the concentration of flammable gas inside the BESS enclosure below 25% LFL by means of a ventilation system. Systems that employ this methodology are required to comply with NFPA 69 design guidelines (Standard on Explosion Prevention Systems).

System description: Although the enclosure dimensions result in a total volume of 31.38 m³, subtracting out the internal components of the cabinet results in an open volume for air of 8.74 m³. The ventilation system is comprised of 2 hydrogen gas sensors and a ventilation system which includes 1 exhaust fan and 2 motorized louver intakes as displayed in **Figure 5-16**. The exhaust fan is manufactured by Nanjing Heben M&E Equipment Technology Co., Model #: TPF13, TPF14; size: 410x360 mm with a rated ideal air flow capacity of 1390 m³/h (820 CFM). The report states that due to the flow restriction of the components inside the container the fan operates at 1020 m³/h (600 CFM). The 1020 m³/h was the flow rate used to run the CFD calculations. DNV finds the noted reduction in flow from ideal to actual to meet expectations.

When a Level-1 gas detection alarm (concentration above 10% LEL) occurs the ventilation system opens the intake louvers and operates the exhaust fan to purge the battery cabinet with ventilation.

Design compliance: Systems that employ methodology described above are required to comply with NFPA 69 design guidelines (Standard on Explosion Prevention Systems). DNV reviewed a CFD (Computational Fluid Dynamics) analysis

report [185] which demonstrates the deflagration prevention system's performance using NFPA 69 guidelines through a set of documented technical assumptions.

The CFD simulation was accompanied by the UL 9540A 4th edition cell, module and unit level test results of SolBank 3.0 associated with EVE cell model # MB31 which includes the flammable gas concentration, number of cell's failure and gas release rate. Based on UL 9540A test results, a total 6 cell's failure scenario resulting in a total of 91.79 LPM gas release rate was assumed in the CFD simulation. The gas release rate was kept constant throughout the simulation as a conservative approach. DNV views the flow modeling decisions to follow reasonable engineering judgement.

Furthermore, 3 gas release positions are identified as at the bottom module of the left rack, middle rack, and right rack of the enclosure. DNV finds the assumptions regarding the gas release positions to be effective for conservative analysis, as the detection location was furthest from the gas release location which introduced delay in detecting. Additionally, this setup is helpful in evaluating the performance of the fan in removing flammable gases from the bottom surfaces.

DNV notes these technical assumptions, gas release location, gas release rate and reduced air flow rate are reasonably go above and beyond the scenario described in UL 9540A testing, and views them favorably.

The simulation results indicate that the ventilation system can maintain the flammable gas concentration below 25% of LFL for all 3 scenarios. While small pockets, higher than 25% of LFL, were observed during these simulations, which DNV views as typical scenario for BESS. Based on the technical assumptions, the CFD analysis report concludes that the ventilation system is designed in accordance with NFPA 69 requirements, DNV takes no exception to these conclusions.

APPENDIX D – CORNEX

DNV leveraged a prior technology review report of Cornex's 314 Ah cell for this section [186].

D.1 Company Evaluation

Cornex New Energy Co., Ltd., established in August 2021 and headquartered in Xiaogan, China, focuses on the R&D, manufacturing, and sales of batteries for various applications, including electric vehicles (EVs), energy storage systems, and passenger and commercial vehicles.

Since its inception, Cornex has built a dedicated R&D team comprising 868 professionals, including 68 Ph.D. holders and 353 employees with master's degrees. The R&D center includes several institutes, such as the New Material Institute, Battery Cell Institute, Simulation Engineering Centre, Energy Storage Pack Institute, EV Pack Institute, and BMS R&D Centre. DNV was informed that these laboratories adhere to China National Accreditation Service (CNAS) laboratory standards, and Cornex expects to receive the official CNAS certificate in June 2024.

Cornex currently operates three battery cell manufacturing facilities with capacities of 10 GWh, 35 GWh, and 55 GWh, respectively, totaling 100 GWh of production capacity [187]. By 2028, Cornex aims to more than triple its production capacity to 350 GWh, while also increasing its use of factory automation [188]. The company's headquarters is based in Wuhan, China, and it has strategically established three manufacturing bases to support its global operations.

D.1.1 Intellectual Property

According to Cornex's company introduction brochure, since August 2021, Cornex has filed a total of 3,003 patents related to lithium-ion batteries, see Figure D-1. Among these, 223 patents are specifically related to the 314 Ah cell. DNV has not reviewed any of these patents in detail.



Figure D-1 An overview of CORNEX's intellectual property

D.1.2 Financial Status

Since Cornex's establishment in August 2021, Cornex has seen noticeable growth in sales revenue of ESS and EV products. According to Cornex, its total sales grew significantly between 2021 and 2023 as shown in Table D-1. The sales figures illustrate that Cornex is currently in a growth phase of development.

DNV requested Cornex's sales figures for 2024 with the breakdown of ESS and EV sales separately by year. DNV will update this information in the next iteration of the Report.

Table D-1 Cornex financial status (2021 to 2023)

Item	2021, in CNY	2022, in CNY	2023, in CNY
Total Sales	210 million	1.40 billion	5.88 billion

D.2 Battery cell specifications

Table D-2 outlines the product technical specifications of Cornex 314 Ah cell.

Table D-2 Cornex's 314Ah cell technical specifications

Parameter	Specification
Cell type / chemistry	Type: Prismatic Chemistry: LFP
Cell model	PF173-314A
Nominal capacity	314 Ah
Operating voltage range	2.5 V to 3.65 V (T > 0 °C) 2.0 V to 3.65 V (T ≤ 0 °C)
Nominal voltage	3.2 V
Nominal energy	1004.8 Wh
AC-impedance	0.16 ± 0.05 mΩ
Maximum charge/discharge current	502.4 W
Discharge end voltage	Not disclosed
Maximum operating temperature range (Charge)	0 °C to 55 °C
Maximum operating temperature range (Discharge)	-30 °C to 60 °C
Optimal operating temperature range (Charge)	15-45 °C
Optimal operating temperature range (Discharge)	15-45 °C
Storage temperature (12 months)	-30 °C ~ 55 °C
Cell dimensions (W x L x H)	71.7±0.5mm × 174.4±0.5mm × 207.2±0.5mm
Weight	5.65 ± 0.1 kg
Energy density	177.84 Wh/kg

Overall, DNV considers Cornex 314 Ah cell specifications to be in line with similar products in industry.

D.3 Performance Evaluation

This section provides an analysis of the performance of Cornex's 314 Ah cells. The assessment is based on a thorough review of the product specifications and test results that were provided by Cornex. All the specifications and performance data were obtained from the test results, which were conducted in Cornex's in-house laboratory.

D.3.1 Capacity

The capacity test results for Cornex's 314 Ah cells, conducted at a 0.5P charge/discharge rate are presented in Table D-3. The measured charge capacities range from 324.21 Ah to 329.94 Ah, while the corresponding discharge capacities are only marginally lower, indicating excellent capacity retention. Capacity efficiency remains above 99.88% in all cases, reflecting minimal losses during the charge-discharge cycle. Energy efficiency, while slightly lower, remains within a narrow band of 94.84% to 95.00%. These results indicate that the Cornex 314 Ah cells exhibit stable performance under standard test conditions.

Table D-3 Cornex 314 Ah Capacity Test Results

No.	C rate	Charge Capacity (Ah)	Discharge Capacity (Ah)	Charge Energy (Wh)	Discharge energy (Wh)	Capacity efficiency	Energy efficiency
#1	0.5P/0.5P	324.2141	323.8315	1091.28	1036.71	99.88%	95.00%
#2	0.5P/0.5P	327.382	327.1556	1102.88	1046.32	99.93%	94.87%
#3	0.5P/0.5P	329.9425	329.6901	1111.89	1054.48	99.92%	94.84%

D.3.2 Power capability and duration

Rate capability in batteries refers to their ability to charge and discharge at different rates without significant performance loss. Temperature significantly impacts this, as higher temperatures typically enhance power capabilities by lowering internal resistance. C-rate indicates the speed at which a cell is charged from 0% SOC to 100% SOC or discharged from 100% SOC to 0% SOC. For example, a 0.5C discharge rate means it takes two hours to fully charge the cell from a fully discharged state. DNV notes that using a cell at a high C-rate can have adverse effects over time and high C-rate can cause particle cracking in the electrode material, leading to rapid degradation.

For cells designed for ESS applications, cell manufacturers more commonly characterize the cells by using constant power rate (P-rate).

Cornex conducted P-rate test according to Chinese national standard GB/T36276 with modifications. DNV reviewed the test results of charge capacity, discharge capacity, charge energy, discharge energy, charge/discharge capacity efficiency, charge/discharge energy efficiency, and temperature rise during discharge. These results are summarized in Table D-4. The capacity efficiency is consistent across all P-rates, with values around 100%. However, the energy efficiency decreases as the P-rate increases, from 96.87% at 0.5P to 93.67% at 2.0P. Additionally, the temperature rise during discharge increases with the P-rate, from 3.5 °C at 0.5P to 4.5 °C at 2.0P.

Overall, Cornex's 314 Ah cell performs well across different P-rates, maintaining high capacity and efficiency. However, the energy efficiency decreases and the temperature rise increases at higher P-rates. This suggests that while the cell can handle higher P-rates, it is more efficient and generates less heat at lower P-rates.

DNV notes that the cells were also tested at a relatively higher 2.0 P-rate than 1.0 P-rate. The charge and discharge curves are shown in Figure D-2 and Figure D-3, respectively. The P-rate test results indicate that Cornex's 314 Ah can be charged and discharged to 100% SOC at 0.5P, 1.0P, and 2.0P.

Table D-4 Cornex's 314 Ah cell P-rate performance

C-rate	Charge Capacity (Ah)	Discharge Capacity (Ah)	Charge Energy (Wh)	Discharge Energy (Wh)	Capacity Efficiency	Energy Efficiency	Temperature rise during discharge (°C)
1.0P/1.0P	326.12	326.96	1095.97	1048.00	100.26%	95.62%	3.9
0.5P/0.5P	328.66	328.88	1096.64	1062.27	100.07%	96.87%	3.5
2.0P/2.0P	328.77	328.60	1113.97	1043.48	99.95%	93.67%	4.5

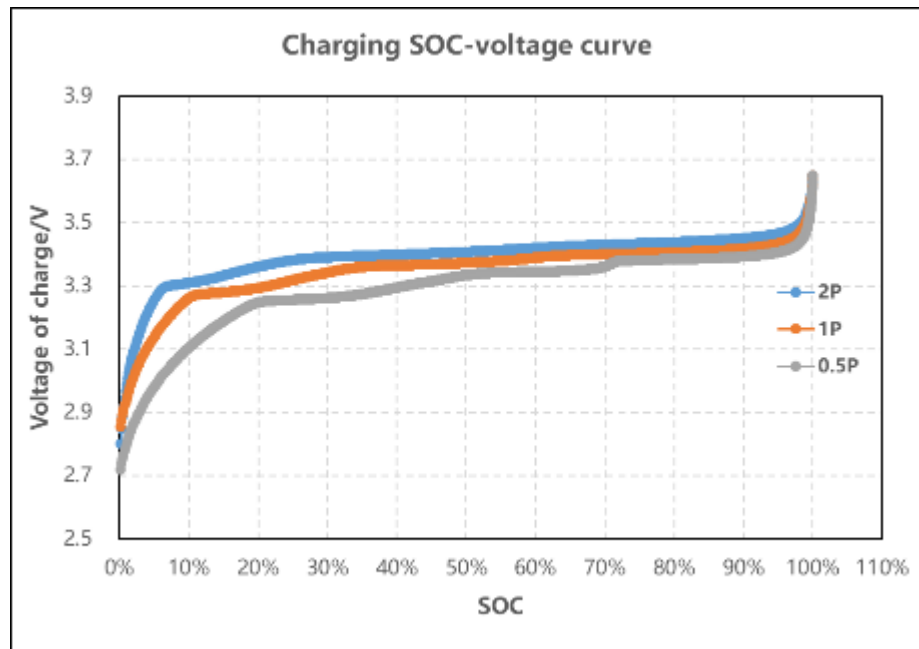


Figure D-2 Charge curves of Cornex's 314 Ah at 0.5P, 1.0P, and 2.0P

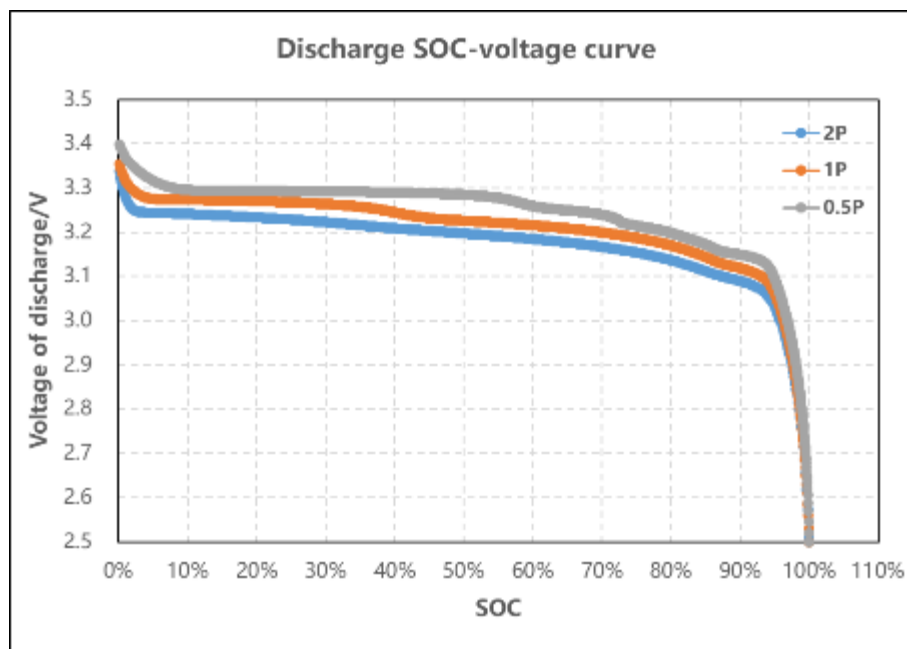


Figure D-3 Discharge curves of Cornex's 314 Ah cell at 0.5P, 1.0P, and 2.0P

DNV reviewed temperature performance of Cornex 314 Ah cell at 5 °C, 25 °C, and 45 °C at 0.5 P-rate, see Table D-5 and Figure D-6 for details.

The test results indicate that at 5 °C, the cell can only discharge 285.77 Ah, resulting in a capacity efficiency of 93.89% and an energy efficiency of 84.89%. At 25 °C, DNV notes that Cornex's 314 Ah cell exhibits typical performance in terms of charge capacity, discharge capacity, efficiency, and temperature rise. At 45 °C, the charge and discharge capacity is higher than at ambient temperature, which is expected because the chemistry is thermodynamically more favorable at 45 °C. However, typically, prolonged operation at 45 °C is not recommended for an LFP cell as it accelerates cell degradation, adversely affecting the cell's cycle life.

Table D-5 Cornex's 314 Ah cell performance at various temperatures

Ambient Temperature	Charge Capacity (Ah)	Discharge Capacity (Ah)	Charge Energy (Wh)	Discharge Energy (Wh)	Capacity Efficiency	Energy Efficiency	Temperature rise during discharge (°C)
5 °C	304.35	285.77	1045.75	887.75	93.89%	84.89%	7.5
25 °C	326.60	327.27	1101.79	1046.61	100.21%	94.99%	3.8
45 °C	334.27	336.80	1120.48	1085.48	100.76%	96.88%	3.2

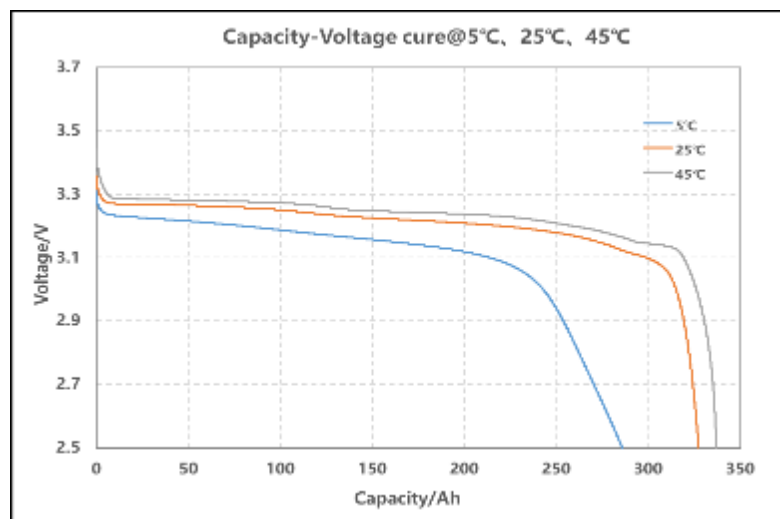


Figure D-4 Discharge curves of Cornex's 314 Ah cell at 5 °C, 25 °C, and 45 °C

D.3.3 Cycle life and capacity retention

Cycle life performance, or degradation, is a measure of cell's product life under certain operating conditions. The indicator of the cycle life performance is the capacity retention, which is calculated as the ratio of discharge capacity of any cycle to the initial discharge capacity at the fresh state. This measure is often known as the state of health.

Cornex provided cycle life test results which were conducted at both 25 °C and 45 °C, as shown in Figure D-5. The experimental data indicates that after 1077 cycles at 25 °C, the capacity retention is 94.63%, while after 1207 cycles at 45 °C, the capacity retention is 87.22%. The graph includes two sets of data points—blue for 25 °C and yellow for 45 °C—

each accompanied by a dashed line representing a modeled degradation trend. The blue dashed line shows a gradual decline in capacity, indicating slower degradation at the lower temperature. In contrast, the yellow dashed line reveals a steeper decline, reflecting accelerated aging at the higher temperature. These modeled trends visually support the experimental data and align with industry expectations, where elevated temperatures typically lead to faster capacity fading. DNV's considers Cornex's cycle life performance is consistent with similar products in the industry.

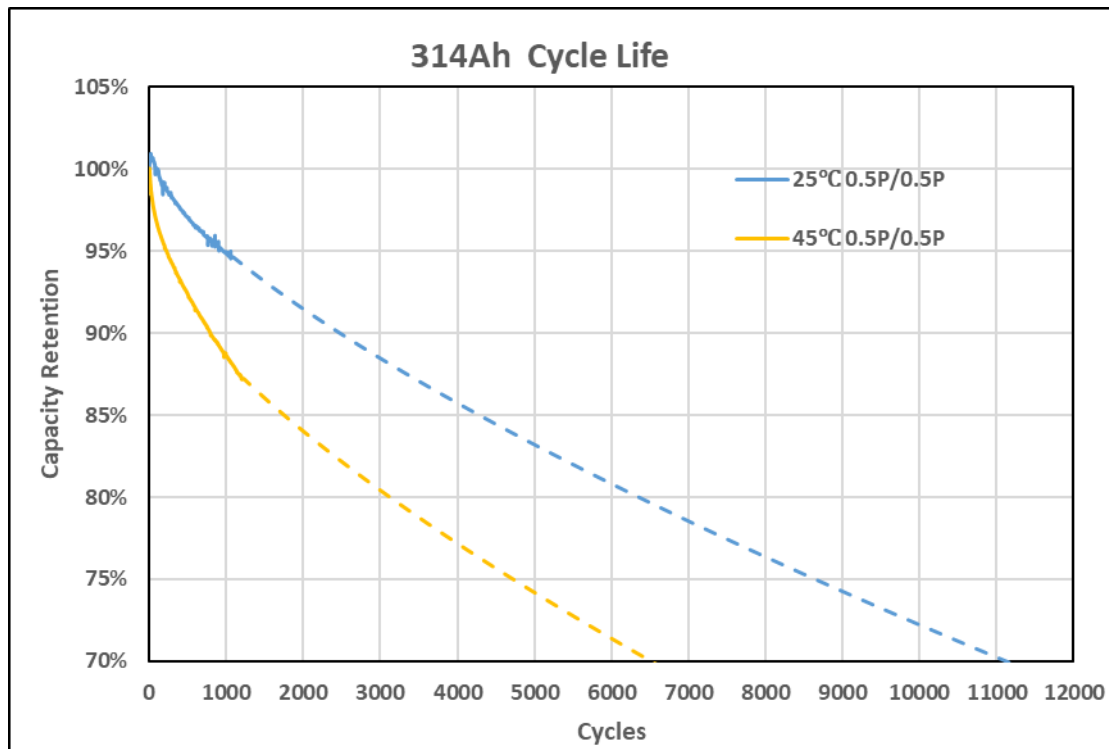


Figure D-5 Cycle life performance of Cornex's 314 Ah cell under 25 °C and 45 °C

D.3.4 Calendar degradation and storage

Calendar degradation refers to the loss of battery capacity and efficiency over time, regardless of cycling activity, primarily due to chemical changes within the cell during storage. The degree of calendric degradation is significantly influenced by the SOC at which the battery is stored and the ambient temperature. The test results illustrate that the impact of SOC and temperature on battery performance, with higher SOC and temperatures leading to more rapid capacity loss over time.

Table D-6 to Table D-7 provides summary results of Cornex's 314Ah storage performance across a wide range of temperatures. At 25 °C, the energy retention is 99.71%, indicating minimal degradation under moderate conditions.

6 months data at -30 °C for shows discharge capacity retention consistently above 99%, and energy efficiency remaining stable around 95%, suggesting the cell is well-suited for cold climate applications. At 45 °C, over 4 months, the cell shows a gradual decline in retention rates, ending at 96.65%, while at 55 °C, over 5 months, the retention drops further to 95.46%, indicating expected thermal stress at elevated temperatures.

While DNV typically requires more than a year of data for full verification, the current dataset shows promising performance and thermal stability. DNV will update its assessment as additional long-term data becomes available.

Table D-6 Cornex's 314 Ah storage performance (50% SOC for 6 months at -30 °C)

Number of months	Charge capacity (Ah)	Discharge capacity (Ah)	Charge energy (Wh)	Discharge energy (Wh)	Capacity efficiency	Capacity efficiency Energy efficiency	Charge capacity retention rate	Discharge capacity retention rate	Charge energy retention rate	Discharge energy retention rate
1	323.8926	323.9831	1090.3172	1037.7120	100.03%	95.18%	99.65%	99.82%	99.54%	99.86%
2	323.5786	323.6601	1089.0699	1038.4131	100.03%	95.35%	99.55%	99.72%	99.42%	99.93%
3	323.1174	323.0822	1088.0138	1035.5741	99.99%	95.18%	99.41%	99.54%	99.33%	99.66%
4	322.6095	322.6152	1085.4079	1034.9020	100.00%	95.35%	99.25%	99.40%	99.09%	99.59%
5	324.6189	325.0616	1098.0565	1049.4246	100.14%	95.57%	99.87%	100.15%	100.24%	100.99%
6	321.8285	321.9188	1083.8557	1032.0216	100.03%	95.22%	99.01%	99.18%	98.95%	99.32%

Table D-7 Cornex's 314 Ah storage performance (50% SOC for 4 months at 25 °C)

Number of months	Charge capacity (Ah)	Discharge capacity (Ah)	Charge energy (Wh)	Discharge energy (Wh)	Capacity efficiency	Capacity efficiency Energy efficiency	Charge capacity retention rate	Discharge capacity retention rate	Charge energy retention rate	Discharge energy retention rate
1	322.0141	322.0074	1084.1328	1032.0852	100.00%	95.20%	99.72%	99.89%	99.97%	100.51%
2	320.8570	320.8416	1080.4927	1027.6389	100.00%	95.11%	99.36%	99.53%	99.63%	100.08%
3	320.9428	320.7799	1081.7362	1030.0220	99.95%	95.22%	99.38%	99.51%	99.75%	100.31%
4	319.2492	319.2750	1074.1303	1023.8133	100.01%	95.32%	98.86%	99.04%	99.05%	99.71%

Table D-8 Cornex's 314 Ah storage performance (50% SOC for 4 months at 45 °C)

Number of months	Charge capacity (Ah)	Discharge capacity (Ah)	Charge energy (Wh)	Discharge energy (Wh)	Capacity efficiency	Capacity efficiency Energy efficiency	Charge capacity retention rate	Discharge capacity retention rate	Charge energy retention rate	Discharge energy retention rate
1	319.9572	320.1024	1077.5321	1025.0944	100.05%	95.13%	98.17%	98.36%	97.97%	98.42%
2	317.5377	317.6203	1068.8507	1017.6222	100.03%	95.21%	97.43%	97.59%	97.18%	97.71%
3	315.8195	315.9569	1062.4752	1012.6162	100.04%	95.31%	96.90%	97.08%	96.60%	97.23%
4	314.4095	314.5671	1057.7163	1008.4861	100.05%	95.35%	96.47%	96.65%	96.17%	96.83%

Table D-9 Cornex's 314 Ah storage performance (50% SOC for 5 months at 55 °C)

Number of months	Charge capacity (Ah)	Discharge capacity (Ah)	Charge energy (Wh)	Discharge energy (Wh)	Capacity efficiency	Capacity efficiency Energy efficiency	Charge capacity retention rate	Discharge capacity retention rate	Charge energy retention rate	Discharge energy retention rate
1	315.1367	315.2219	1061.0841	1009.2336	100.03%	95.11%	97.06%	97.23%	96.86%	97.24%
2	310.6279	310.9312	1045.5768	996.0558	100.10%	95.26%	95.67%	95.90%	95.44%	95.97%
3	309.2008	309.4486	1040.8735	991.2220	100.08%	95.23%	95.23%	95.45%	95.01%	95.50%
4	310.0194	310.6438	1049.7690	1000.6583	100.20%	95.32%	95.48%	95.82%	95.82%	96.41%
5	308.8448	309.4923	1045.6924	997.1444	100.21%	95.36%	95.12%	95.46%	95.45%	96.07%

Table D-10 IEC test reports and certificates list (Cornex cell)

Component	Test standard	Certification/Test verified
Unit	IEC 63056	The unit model # CSI-SolBank-R-418-2h-N and CSI-SolBank-R-418-4h-N have obtained IEC 62619 certificate issued by TUV Rheinland [189] [190]
Unit	IEC 62619	The unit model # CSI-SolBank-R-418-2h-N and CSI-SolBank-R-418-4h-N have obtained IEC 63056 certificate issued by TUV Rheinland [189] [190]
Integrated BESS	IEC 62477	The BESS model # CSI-SolBank-S-5016-2h-EU and CSI-SolBank-S-5016-4h-EU (Cornex cell) have obtained IEC 62477 certificate issued by TUV Rheinland [191]
Integrated BESS	Low Voltage Directive (EU) 2014/35	The BESS model # CSI-SolBank-S-5016-2h-EU and CSI-SolBank-S-5016-4h-EU (Cornex cell) have obtained Low Voltage Directive (EU) 2014/35 certificate of Conformity issued by TUV Rheinland [192]
Integrated BESS	IEC 61000	The BESS model # CSI-SolBank-S-5016-2h-EU and CSI-SolBank-S-5016-4h-EU (Cornex cell) have obtained IEC 61000 certificate by TUV Rheinland [193]
Cell	IEC 62619	The cell model # PF173-314A has obtained test report issued by TUV Rheinland [194]
Cell	UN38.3	The cell model # PF173-314A has obtained UN38.3 test report issued by TUV Rheinland [195]
Integrated BESS	UN 38.3	The BESS model #CSI-SolBank-S-5016-2h-NA and CSI-SolBank-S-5016-4h-NA have been tested with UN38.3 requirements and test report issued by CVC Testing Technology Co., Ltd [196] [197]

D.4 UL 9540A testing

UL 9540A testing is a destructive test method used for evaluating the thermal runaway impacts in a BESS and gathering data to assist in assessing or developing mitigation measures for the failure event, propagation of the failure, or consequences of an event, such as an explosion or fire. The test, which does not have pass/fail criteria, can be performed on a cell, module, or unit level. UL 9540A is ANSI (American National Standards Institute) accredited and is currently considered to be the most appropriate published methodology to provide comprehensive, consistent, and reliable third-party data for battery failure testing. DNV notes that UL 9540A is a requirement for the UL 9540 certification mandated by code in Section 1207.11.1 of the 2024 IFC.

The following sections summarize the cell, module and unit level tests.

D.4.1 Cell-level results

DNV has reviewed the 4th edition of the UL 9540A cell level test report [76] bearing model number PF173-314A. At the cell level, UL 9540A tests whether thermal runaway can occur in a single cell and provides insights into onset temperatures for venting and thermal runaway as well as off-gas composition and volume. To provide comparison and benchmarks, DNV has reviewed test reports for cells that were conducted under the same or similar conditions for cells with similar chemistry, capacity and form factor.

Test method and deviations: DNV notes that the cell venting and thermal runaway temperatures reported were not recorded from under the heater as required by section 7.3.1.7 of UL 9540A 4th edition test methodology. This will likely cause the reported temperatures to be lower than what has been reported for similar cells in the industry.

Venting and thermal runaway temperatures: The cell venting temperature and thermal runaway temperature were 157.0 °C and 236.0 °C, respectively. DNV notes that the cell venting temperature is below average, while the thermal runaway temperature is higher than what DNV typically observes for LFP battery chemistry. The cells displayed a difference of roughly 79 °C between the temperature at cell venting and thermal runaway. DNV views the wide cell venting and thermal runaway temperature difference as beneficial for the cell as there is more of an inherent barrier in place for increasing temperatures and may provide enough time for safety systems to detect and respond to thermal events. Additionally, DNV reviewed the BMS setting which is configured in such a way that if cell temperature exceeds 55 °C, the charging/discharging is prohibited and if cell temperature exceeds 58 °C, the BMS will disconnect the contactor within the BESS. Hence the battery will be isolated well before the cell venting temperature [88].

Gas composition and volumes: In comparison with other tests DNV has reviewed that were conducted under the same or similar conditions, the gas composition reported for the Cornex cell has a slightly lower proportion of H₂. In general, however, the amount of hydrogen produced could qualitatively relate to an energetic explosion, although a detailed quantitative analysis of this data would be necessary to determine the impact. A total of 190.7L of gas was produced during the test. The volume of gas produced was lower on a per-Amp-hour basis. This may be a product of the form factor of the cell but would contribute favorably to the safety of the cell. Additionally, the BESS is equipped with gas detection systems, enhancing safety by identifying off-gassing and enabling early detection, which helps mitigate cell thermal events before they escalate to thermal runaway.

Performance criteria: DNV notes that the UL 9540A test method stipulates that the cell level test should meet the following two performance criteria: thermal runaway should not be induced, and off-gassing event should not produce flammable gases. Since flammable gases were produced which is typical for LFP cell chemistry, the cell level test did not meet the

performance criteria. Hence DNV recommends that the battery modules utilizing this cell, shall be subjected to UL 9540A module level test.

D.4.2 Module-level results

DNV has reviewed the 4th edition of the UL 9540A module level test report [77] bearing model number CSI-SolBank-P-104.5-2h-N, CSI-SolBank-P-104.5-4h-N. The module level test provides insights into how thermal runaway propagates from a single failed cell to adjacent cells in a module. The test results help designers optimize module design and validate safety systems in the BESS.

Test method and deviations: DNV did not identify deviations from the test method described in UL 9540A 4th edition, section 8.

Observation: The test results indicated that no fire, flames, flying debris, explosive discharge, sparks, electrical arcs or re-ignitions observed. The test report stated that three initiating cells went under thermal runaway and propagation occurred to two additional adjacent cells. However, Figure D-6 indicates that one cell was placed under heaters on both larger surface sides of the cell. Therefore, it should be interpreted as one cell was initiated with two heaters and cell-to-cell propagation occurred to four additional adjacent cells.



Figure D-6 Initiating cell and heaters location in battery module

In addition, the test report stated that 392.60 L of hydrogen, 189.92 L of carbon monoxide, 207.33 L of carbon dioxide and 364.38 L of hydrocarbons gases were generated during the test. Hydrogen and hydrocarbons, such as methane and propane, are explosive and flammable gases. In addition, carbon monoxide is an extremely flammable gas that can readily form an explosive mixture with air. Carbon dioxide is also an asphyxiant.

Performance criteria: DNV notes that the UL 9540A test method stipulates that the module level test should meet the following two performance criteria: thermal runaway should be contained within module, and off-gassing event should not produce flammable gases. Since flammable gases were produced in cell level testing, the module level test did not meet the performance criteria. Hence DNV recommends that the battery modules utilizing this cell, shall be subjected to UL 9540A unit level test

D.4.3 Unit-level results

CSI has tested their BESS Unit, bearing model number CSI-SolBank-R-418-2h-N, CSI-SolBank-R-418-4h-N, to the 4th edition of the UL 9540A test methodology. TUV Rheinland conducted the unit level test [78]. UL 9540A unit tests provide insight into thermal runaway propagation beyond the single module to affect an entire unit.

BESS unit description: UL 9540A article 9.1.2 specifies that the unit level test requires initiating an internal fire (per the module level test procedure) in one BESS unit to assess fire propagation to adjacent, representatively installed BESS units. For the purposes of the test, a Unit was considered as open rack configuration which includes 4 battery modules and 1 control unit. Figure D-7 displays the location of the initiating module during unit level testing.

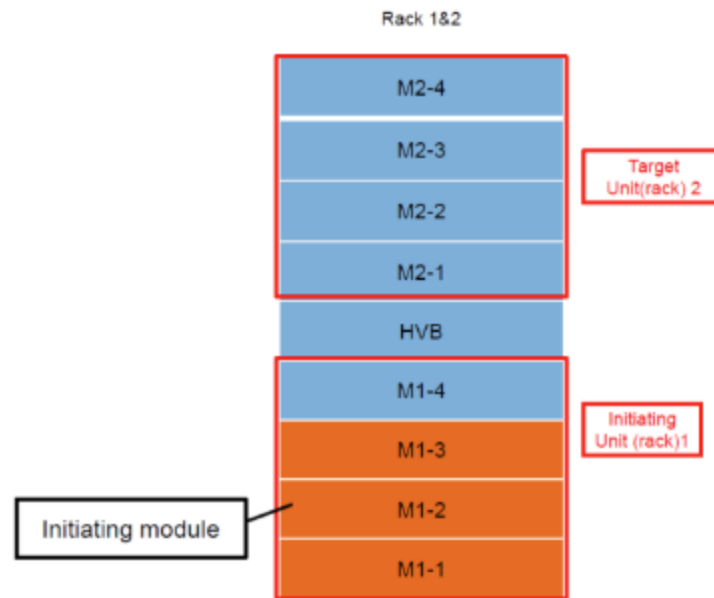


Figure D-7 Initiating module location in unit level testing

Test method and deviations: In the Unit level test, a complete BESS Unit is installed and surrounded by target (dummy) BESS and walls at the distance intended in its installation. Thermal runaway is induced in battery cells of one of the modules in the initiating BESS unit. The results are intended to report whether a fire or thermal runaway will propagate between modules and other Units, and whether there will be flying debris or explosive discharge of gas. The 4th edition UL 9540A unit-level methodology outlines procedures for different types of installation including indoor and outdoor ground mounted systems. The test report indicates this unit has been tested for non-residential indoor floor mounted use. The text of UL 9540A allows the BESS to be tested with its integral fire protection system provided by the manufacturer in the test set up. However, no fire protection system was utilized during the test.

The following provides an overview of the test set up:

- Three instrumented walls (at least 0.61 m taller than unit height and 0.49 m extended up to exterior target unit) were constructed to form a perimeter around three sides of the initiating and target units. The walls were constructed covered with 16 mm gypsum wall board and painted flat black.
- 4 Units were used for this test (see Figure D-8 for arrangement).
- The minimum separation distance from the unit to wall and between units is displayed in Figure D-8. Customer indicated that the separation distance between the initiating unit and target unit is 601 mm [161].

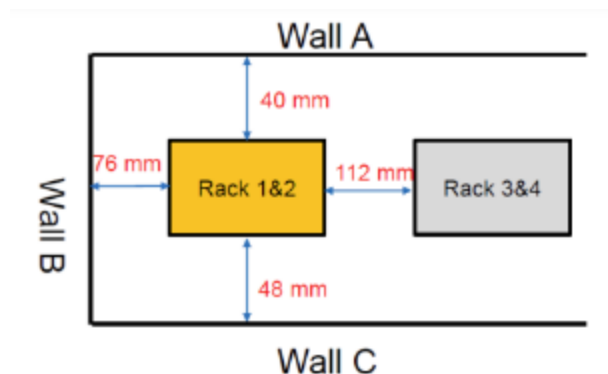


Figure D-8 Unit level test setup

Observations and performance criteria: During the tests, no flaming explosive hazards, including deflagration or detonation, were observed. Furthermore, during the test no flying debris, sparking, electrical arcs, or other electrical events occurred or were observed. The test report stated that three initiating cells went under thermal runaway and cell-to-cell thermal runaway propagation occurred to additional two adjacent cells. However, Figure D-9 indicates that one cell was placed under heaters on both larger surface sides of the cell. Therefore, it should be interpreted as one cell was initiated with two heaters and cell-to-cell propagation occurred to four additional adjacent cells.

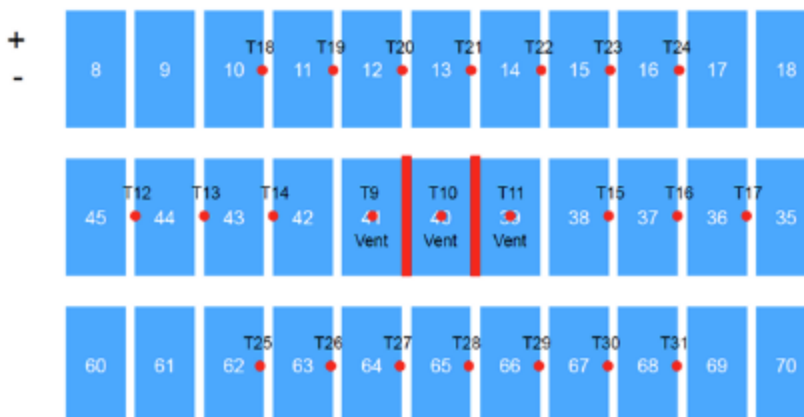


Figure D-9 Initiating cell and heaters location in battery module

During the test, 273.54 L of hydrogen, 139.64 L of carbon monoxide, 246.11 L of carbon dioxide and 312.32 L of hydrocarbons gases were produced. Table D-11 provides an overview of the performance conditions set forth by UL 9540A in addition to the summary of the Unit test observations.

Table D-11 UL 9540A Unit performance criteria for indoor floor mounted BESS

Performance condition	Test observation/remark
Flaming outside the initiating BESS unit is not observed	Meets the performance criteria. No flaming was observed internally or externally of the Unit during the test.

Performance condition	Test observation/remark
Surface temperatures of modules within the target units adjacent to the initiating unit do not exceed the temperature at which thermally initiated cell venting occurs, as determined in 7.3.1.8.	Meets the performance criteria. The maximum surface temperature measured on target Unit was 35.7 °C, far below the cell venting temperature of 157 °C reported in the cell-level test.
For units intended for installation in locations with combustible constructions, surface temperature measurements on wall surfaces do not exceed 97 °C of temperature rise above ambient temperature per 9.2.15.	Meets the performance criteria. The maximum surface temperature on the adjacent walls was 36.9 °C, below the 97 °C temperature rise performance criteria.
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.	Meets the performance criteria. Explosion hazards were not observed during the test (internal and external).
Heat flux in the center of the accessible means of egress shall not exceed 1.3 kW/m ²	Meets the performance criteria. Maximum ~0.85 kW/m ² heat flux detected on instrument wall.

While cell-to-cell propagation occurred during the test, module-to-module and unit-to-unit propagation was not observed indicating an adequate thermal barrier between modules. The Unit level results show a resiliency of the Unit to thermal runaway propagation and fire hazard in a single failure event. The unit level performance criteria have been met, therefore, the tested spacing distances can be used as the minimum spacing for the BESS installation.

D.5 Explosion prevention

Methodology: The explosion/deflagration prevention system is designed to reduce the concentration of flammable gas inside the BESS enclosure below 25% LFL by means of a ventilation system. Systems that employ this methodology are required to comply with NFPA 69 design guidelines (Standard on Explosion Prevention Systems).

System description: Although the enclosure dimensions result in a total volume of 31.38 m³, subtracting out the internal components of the cabinet results in an open volume for air of 8.74 m³. The ventilation system is comprised of 2 hydrogen gas sensors and a ventilation system which includes 1 exhaust fan and 2 motorized louver intakes, as displayed in **Figure 5-16**. The exhaust fan is manufactured by Nanjing Heben M&E Equipment Technology Co., Model #: TPF13, TPF14; size: 410x360 mm with a rated ideal air flow capacity of 1390 m³/h (820 CFM). The report states that due to the flow restriction of the components inside the container the fan operates at 1020 m³/h (600 CFM). 1020 m³/h was the flow rate used to run the CFD calculations. DNV finds the noted reduction in flow from ideal to actual to meet expectations.

Design compliance: Systems that employ methodology described above are required to comply with NFPA 69 design guidelines (Standard on Explosion Prevention Systems). DNV reviewed a CFD analysis report [198] which demonstrates the deflagration prevention system's performance using NFPA 69 guidelines through a set of documented technical assumptions.

The CFD simulation was accompanied by the UL 9540A 4th edition cell, module and unit level test results of SolBank 3.0 associated with Cornex cell model # PF173-314A which includes the flammable gas concentration, number of cell's failure and gas release rate. Based on UL 9540A test results, a total 5 cell's failure scenario and a total of 131.62 LPM gas release rate were assumed in the CFD simulation. The gas release rate was kept constant throughout the simulation as a conservative approach. DNV views the flow modeling decisions to follow reasonable engineering judgement.

Furthermore, 3 gas release positions are identified as at the bottom module of the left rack, middle rack, and right rack of the enclosure. DNV finds the assumptions regarding the gas release positions to be effective for conservative analysis, as the

detection location was furthest from the gas release location which introduced delay in detecting. Additionally, this setup is helpful in evaluating the performance of the fan in removing flammable gases from the bottom surfaces.

DNV notes these technical assumptions, gas release location, gas release rate and reduced air flow rate are reasonably go above and beyond the scenario described in UL 9540A testing, and views them favorably.

The simulation results indicate that the ventilation system can maintain the flammable gas concentration below 25% of LFL for all 3 scenarios. While small pockets, higher than 25% of LFL, were observed during these simulations, which DNV views as typical scenario for BESS. Based on the technical assumptions, the CFD analysis report concludes that the ventilation system is designed in accordance with NFPA 69 requirements, DNV takes no exception to these conclusions.

D.6 Explosion protection

Methodology: Explosion protection for this BESS is achieved through deflagration venting as described in NFPA 68:2023, Chapter 6. In simple terms, if flammable gases released during a battery thermal runaway event ignite inside the sealed container, lightweight vent panels (rupture diaphragms) mounted on the enclosure walls burst open at a preset pressure (0.1 bar-g), allowing the expanding combustion gases and pressure to escape outward before the internal pressure exceeds the structural capacity of the container. The design objective is to ensure that the reduced explosion pressure inside the enclosure (Pred) remains below a safe fraction of the container's ultimate structural strength, thereby preventing catastrophic failure.

System Description: The system under evaluation is the CSI SolBank S-5016 series, a containerized DC battery energy storage system housed in a standard 20-foot-equivalent enclosure measuring 6058 × 2438 × 2896 mm. The overall internal volume of the battery cabinet is reported as 31.38 m³, with an effective open internal volume (after subtracting racks, modules, and structural elements) of 8.74 m³. Five deflagration vent panels manufactured by BasCo (model EPS-CP-610×610) are installed on the container roof. Each panel provides an effective vent area of 0.610 × 0.610 m (0.372 m²), yielding a total vent area of approximately 1.861 m². The panels are rupture diaphragm-type devices that activate at a static opening pressure (Pstat) of 0.1 bar-g.

Technical Assumptions: The labeling of one vent panel as "optional" on the layout drawing is a concern as the CFD analysis should clarify whether all five panels or only four were modeled, as removing one panel reduces the total vent area by 20% and could meaningfully change the pressure outcome. The report does not explicitly state how many panels were active in the simulation. Several conservative assumptions build meaningful engineering margin. Using the highest gas mass among the three test levels is appropriately conservative.

The worst-case scenario produces 0.351 bar-g against an allowable Pred of 0.367 bar-g implies that the margin is only 0.016 bar-g, or approximately 4.6% which is a tight margin for deflagration venting design. Secondly, the enclosure mechanical analysis was provided by CSI (the client), not independently verified by TUV Rheinland. This means the 0.55 bar-g ultimate strength, which directly determines the pass/fail threshold rests on client-provided data. An independent structural assessment or third-party verification of this value would significantly strengthen the overall safety case.

Conclusions: The overall compliance conclusion per the report is that the design meets NFPA 68:2023 Chapter 6 requirements, though the tight structural margin of 4.6% and the absence of independent enclosure strength verification represent areas where additional substantiation would be beneficial.

APPENDIX E – SUNWODA

DNV leveraged a prior technology review report of Sunwoda's 314 Ah cell for this section [199].

E.1 Company Evaluation

Sunwoda Electronic Co., Ltd. ("Sunwoda"), founded in 1997 and headquartered in Shenzhen, China is a global leader in lithium-ion battery technology with over 27,500 employees worldwide. In 2008, it launched its EV and ESS battery division under Sunwoda Mobility Energy Technology Co., Ltd., a wholly owned subsidiary focused on R&D, design, production, and sales of lithium-ion battery cells, modules, BMS, and packs. Sunwoda Group operates across six major business segments: Mobility Battery (its traditional core business for mobile and consumer electronics), EV Battery (providing solutions for electric vehicles), Intelligent Devices (smart hardware for VR, drones, and smart homes), ESS (energy storage systems for various sectors), Intelligent Manufacturing & Industrial Internet (digital twin and automation solutions), and Testing Services (certified testing for various battery types).

Figure E-1 shows the current lithium-battery supply chain, from raw materials production to cell recycling. The Sunwoda upstream business strategy includes key links such as mineral raw materials and battery materials (anode, cathode, electrolyte, and separator), battery cells, pack, and BMS while the downstream includes electric vehicles, energy storage stations, cell recycling and power battery echelon utilization. DNV notes that the EV and ESS business development strategies form a business blueprint for the integration of the entire industry chain. DNV considers that the EV and ESS strategy is a holistic approach that covers the majority of the lithium-ion battery ecosystem.

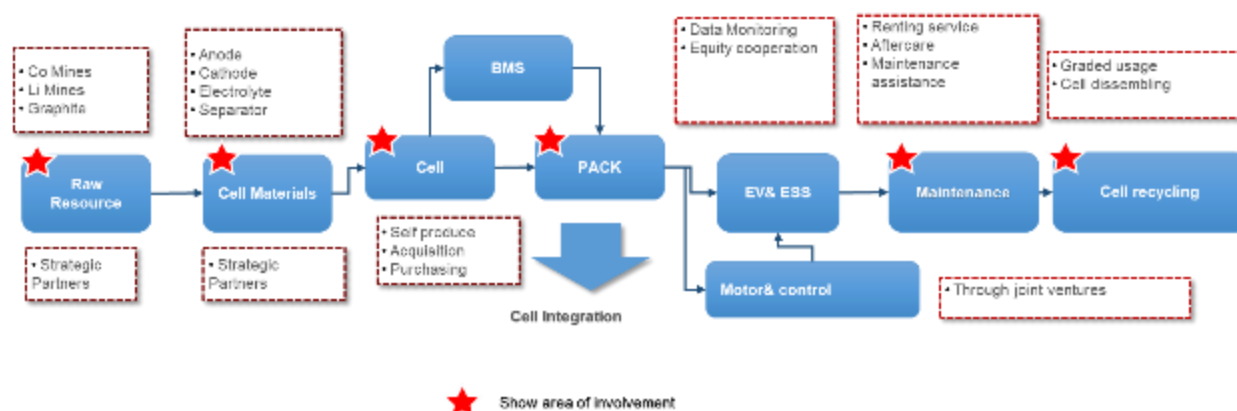


Figure E-1 Lithium-ion battery supply chain and Sunwoda Group's involvement

Sunwoda product roadmap is shown in Figure E-2. Sunwoda aims to develop high-performance LFP battery cells that are safe, affordable, and sustainable with a long lifetime. The ESS cell roadmap advocates the planning of sodium-ion batteries in 2023 and plans to improve energy density and life cycle in the long term to develop a low-cost alternative to lithium-ion batteries.

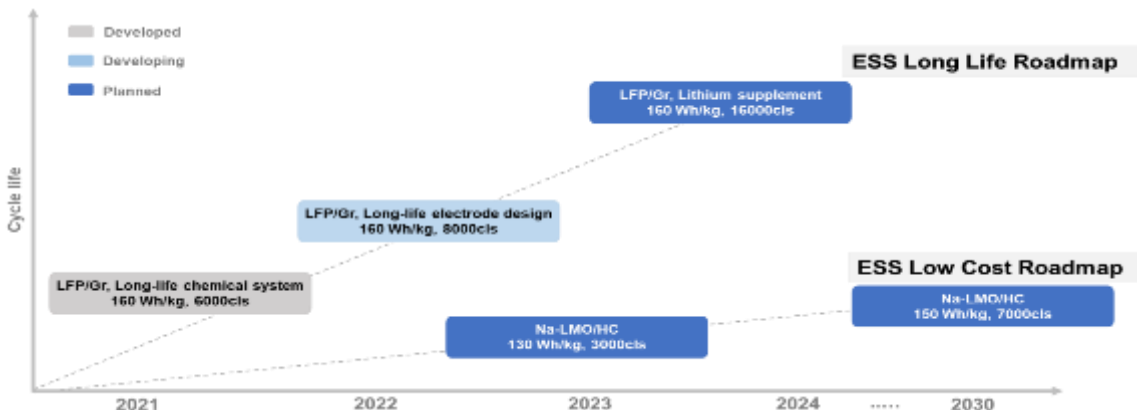


Figure E-2 Product development roadmap of Sunwoda's cell products

Sunwoda has set up 12 manufacturing bases worldwide with 10 manufacturing bases in China such as Shenzhen, Huizhou, Nanjing, Lanxi, Zaozhuang, Nanchang, Shifang, as well as one in New Delhi, India and one in Haiphong, Vietnam. Sunwoda has also established technical centers and customer service centers in Los Angeles, CA, USA, Tel Aviv, Israel and Hamburg, Germany. The EV battery manufacturing plants and R&D centers are mainly clustered in China. The company has established an Indian subsidiary in New Delhi and started a new chapter of globalization [1]. Sunwoda has developed different LFP and NMC (nickel manganese cobalt oxide) battery cells for different applications based on their cell's characteristics, such as for EV which can support super-fast and fast charging, hybrid electric vehicle (HEV) which can support high power applications, and for ESS which covers wide operation characteristics such as renewable energy system integration, residential energy storage, and backup power for data centers.

E.1.1 Intellectual Property

Sunwoda provided a list of issued patents with publication number for EV battery and an overview is presented in Figure E-3. As of 31 December, 2022, Sunwoda Group applied for 1,813 patents, accounting for 33% of inventions. A total of 874 patents were granted, 12 of which are appearance design patents, 65 invention patents and 797 utility patents. Patents cover many aspects of battery technology from materials to applications, mainly focusing on cell structure, materials, BMS, processes, equipment, and testing methods. DNV has not reviewed any particular patent applications associated with the 314 Ah cell.

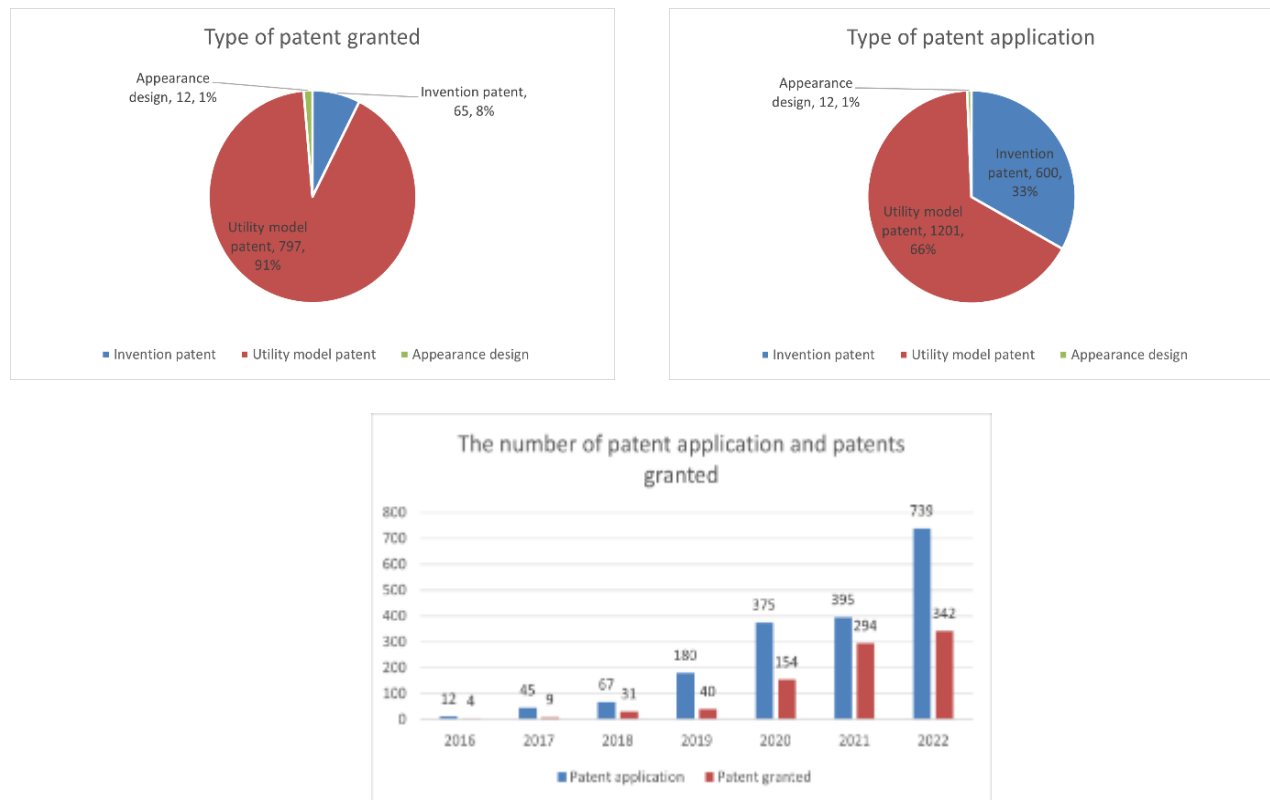


Figure E-3 Statistics of Sunwoda's patents applied and granted

E.1.2 Financial Status

Sunwoda has provided year-on-year revenue from 2011 to 2022, which is summarized in Figure E-4. The revenue of Sunwoda Group has grown over 30% from USD 5.7 Billion to USD 7.6 Billion from 2021 to 2022, which was significantly impacted by increased sales in EV battery products as well ESS from both domestic and overseas market. The compound annual growth rate (CAGR) reached 41.82%. Sunwoda shipped 9.23 GWh in EV battery products in 2022, which resulted in a three times increase in EV battery annual revenue of Sunwoda from RMB 2.93 billion in 2021 to RMB 13 billion. DNV notes that Sunwoda shows a significant amount of growth each year. DNV was not able to review the financial status of Sunwoda Mobility Energy Technology Co., Ltd separately. Sunwoda has not provided the most up to date financial information up to 2025.



Figure E-4 The growth of Sunwoda Group's revenue from 2011 to 2022

E.2 Battery cell specifications

Figure E-5 presents prismatic Sunwoda's 314 Ah LFP cell. The cell specifications are presented in Table E-1, which includes several parameters such as capacity, operating voltage and operating temperature conditions [145].

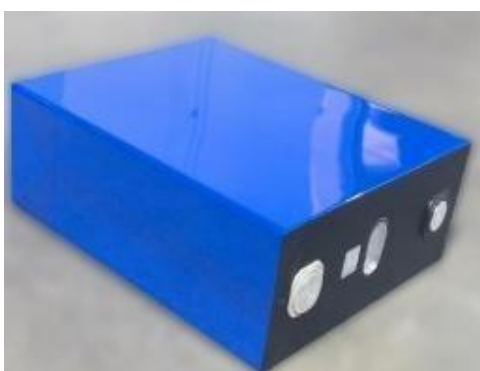


Figure E-5 Sunwoda's 314 Ah LFP cell

Table E-1 Sunwoda 314 battery cell specifications

Parameter	Specification
Cell type / chemistry	Type: Prismatic Chemistry: LFP
Cell model	SBP-01-3140
Nominal capacity	314 Ah
Operating voltage range	2.5 V to 3.65 V (T > 0 °C) 2.0 V to 3.65 V (T ≤ 0 °C)
Nominal voltage	3.2 V
Nominal energy	1004.8 Wh

Parameter	Specification
AC-impedance	< 0.21 mΩ
Maximum charge/discharge current	157 A
Discharge end voltage	2.5V (T>0 °C) 2.0V (T≤0 °C)
Maximum operating temperature range (Charge)	0 °C to 60 °C
Maximum operating temperature range (Discharge)	-30 °C to 60 °C
Optimal operating temperature range (Charge)	25 °C to 35 °C
Optimal operating temperature range (Discharge)	25 °C to 35 °C
Storage temperature (12 months)	-40 °C to 60 °C
Cell dimensions (W x L x H)	71.5 mm × 174.3 mm × 204.3 mm
Weight	5.60 ± 0.15kg
Energy density	≥ 175 Wh/kg

DNV requested supporting data for storage specification of -40 °C to 60 °C and recommends updating it once the information is available.

E.3 Performance Evaluation

This section provides an analysis of the performance of Sunwoda's 314 Ah cells. The assessment is based on a thorough review of the product specifications and test results that were provided by Sunwoda. All the specifications and performance data were obtained from the test results, which were conducted in Sunwoda's in-house laboratory.

E.3.1 Capacity

The capacity test was conducted by following test conditions – the cell was charged to 3.65 V and discharged to 2.5 V, which corresponds to 100% depth of discharge (DOD). The charge and discharge rates are 0.5P/0.5P. The test was conducted at an ambient temperature of 25 °C. Figure E-6 shows the charge and discharge curves of capacity performance, which indicates that discharge capacity and discharge energy are 326.3 Ah and 1043.4 Wh, respectively. DNV noted that both parameters exceed the nominal capacity and nominal energy specified in the technical specifications.

DNV requested RTE data for the capacity test for EVE cell and recommends updating it once the information is available.

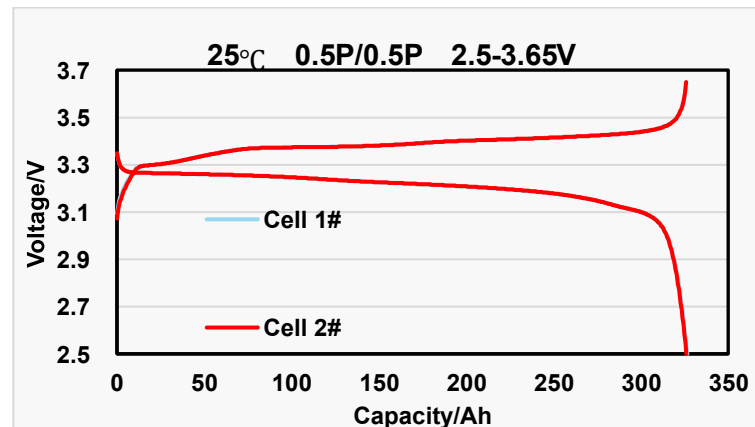


Figure E-6 Sunwoda's 314 Ah cell charge and discharge curves.

E.3.2 Power capability and duration

Rate capability in battery cells refers to their ability to charge and discharge at different rates without significant performance loss. Temperature significantly impacts this, as higher temperatures typically enhance power capabilities by lowering internal resistance. C-rate indicates the speed at which a cell is charged from 0% SOC to 100% SOC or discharged from 100% SOC to 0% SOC. For example, a 0.5C discharge rate means it takes two hours to fully charge the cell from a fully discharged state. DNV notes that using a cell at a high C-rate can have adverse effects over time and high C-rate can cause particle cracking in the electrode material, leading to rapid degradation.

For cells designed for BESS applications, cell manufacturers more commonly characterize the cells by using constant power rate (P-rate). Sunwoda conducted the P-rate test according to protocol as per Chinese national standard GB/T36276-2018, which is detailed as follows:

- Cell is charged to 3.65V by 0.2P at 25 °C (controlled temperature throughout the test)
- Rest for 30 minutes
- Cell is discharged to 2.5V by 0.1P
- Rest for 120 minutes
- Cell is charged to 3.65V by xP (x = 0.25, 0.5, and 1.0)
- Rest for 30 minutes
- Cell is discharged to 2.5V by xP (x = 0.25, 0.5, and 1.0)
- Charge and discharge loop until all x-values are completed

The P-rate test results are shown in Figure E-7, which indicate Sunwoda's 314 Ah can be charged and discharged to 100% SOC at 0.25P, 0.5P, and 1.0P rates. DNV notes that higher discharge rates theoretically result in lower discharge capacities, which is considered typical for LFP prismatic cells.

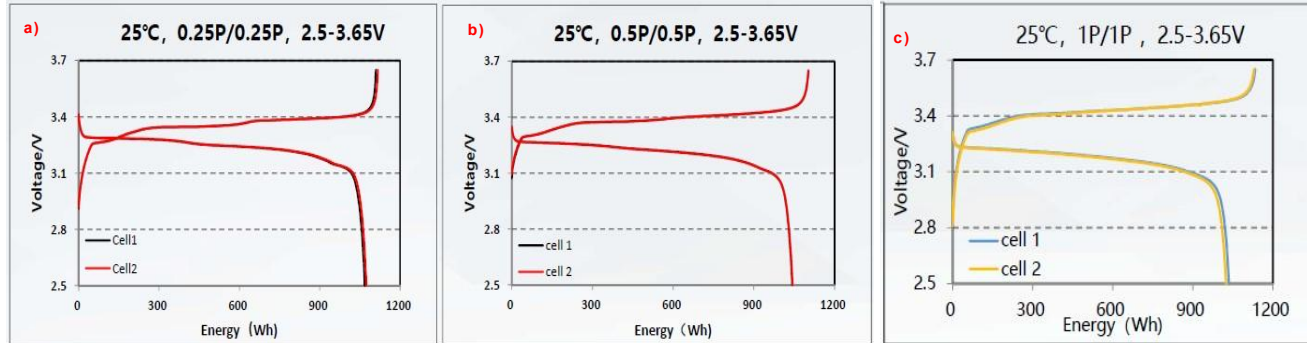


Figure E-7 Charge curves at various P-rates: a) 0.25P; b) 0.5P; c) 1.0P

DNV reviewed the temperature performance of Sunwoda's 314 Ah cell across a range of ambient temperatures: 55 °C, 45 °C, 35 °C, 25 °C, 10 °C, 0 °C, -10 °C, -20 °C, and -30 °C. The test procedures were as follows:

- At 25 °C:
 - The cell was charged to 3.65V at 0.5P and 25 °C.
 - It was then rested for 30 minutes.
 - The cell was discharged to 2.5V at 0.5P.
- At 55 °C, 45 °C, 35 °C, 10 °C, and 0 °C:
 - The cell was charged to 3.65V at 0.5P and 25 °C.
 - It was then rested at the target temperature (T °C) for 4 hours.
 - The cell was discharged to 2.5V at 0.5P.
 - This process was repeated for each temperature.
- At -10 °C, -20 °C, and -30 °C:
 - The cell was charged to 3.65V at 0.5P and 25 °C.
 - It was then rested at the target temperature (T °C) for 6 hours.
 - The cell was discharged to 2.0V at 0.5P.
 - This process was repeated for each temperature.

Figure E-8 shows the charge and discharge curves of Sunwoda's 314 Ah cell at various temperatures. The results indicate that discharge capacity increases at elevated temperatures (35 °C, 45 °C, and 55 °C) due to enhanced reaction kinetics. However, prolonged operation at 45 °C or 55 °C is not recommended, as high temperatures accelerate cell degradation mechanisms.

Conversely, when cell temperatures fall below 0 °C during standalone testing, discharge capacity and curve stability deteriorate, consistent with the known low-temperature behavior of LFP chemistry. This behavior is accompanied by elevated cell temperature rise due to increased internal resistance. In system-level applications such as SolBank 3.0, coordinated BMS and TMS controls are designed to maintain cell temperatures within an optimal operating range, thereby limiting exposure to sustained sub-zero operating conditions and mitigating the associated performance impacts.

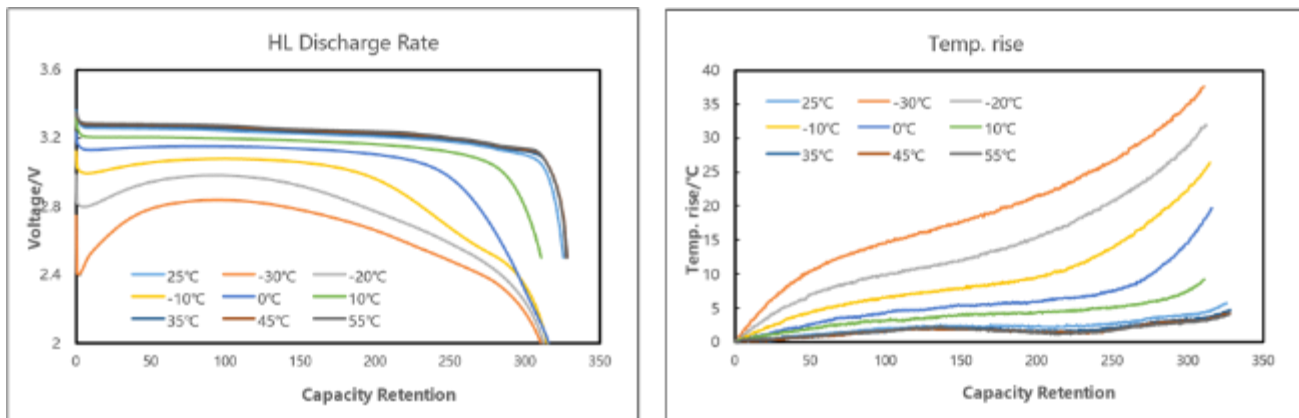


Figure E-8 Discharge and charge curves at various temperatures

E.3.3 Cycle life and capacity retention

Cycle life performance, or degradation, is a measure of cell's product life under certain operating conditions. The indicator of the cycle life performance is the capacity retention, which is calculated as the ratio of discharge capacity of any cycle to the initial discharge capacity at the fresh state. This measure is often known as the state of health (SOH).

Sunwoda conducted a cycle life test. The cells were charged and discharged by 0.5P for 30 minutes at 25 °C and 10 minutes at 45 °C, respectively, between each cycle. Figure E-9 shows that Sunwoda's 314 Ah cell retained 96.74% of its initial capacity after 560 cycles at 25 °C, under the standard charge and discharge protocol. At 45 °C, Sunwoda's 314 Ah cell retained 91.44% of its initial capacity after 671 cycles. Comparing the data collected after 500 cycles at both temperatures, the capacity retention at 25 °C was significantly higher than that at 45 °C.

This outcome is typical for LFP cell chemistry since cell degradation mechanisms accelerate at higher temperatures. According to the simulation results (dashed lines in Figure E-9), Sunwoda concluded that the 314 Ah cell will reach 62.50% retention after 10000 cycles. The simulation result indicates that Sunwoda's 314 Ah cell can retain approximately 60% SOH after 10,000 cycles under 25 °C, which meets its product specifications. DNV notes that it is essential for Sunwoda to continuously validate the predicted cell degradation curve as additional cycle data become available to ensure more accurate and reliable degradation expectations.

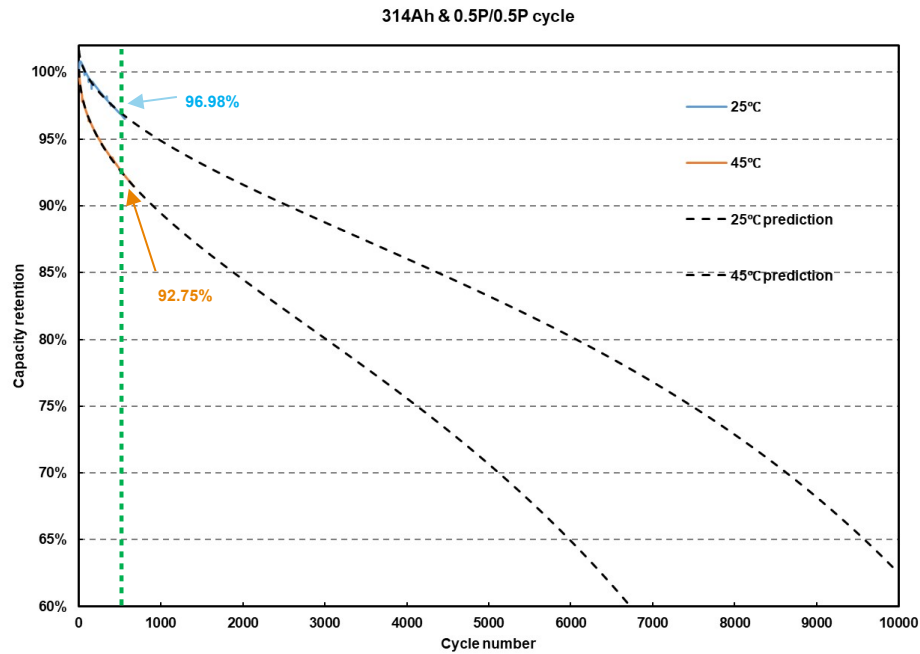


Figure E-9 Cycle life test (experimental and simulation)

E.3.4 Calendar degradation and storage

Calendar degradation refers to the loss of battery capacity and efficiency over time, regardless of cycling activity, primarily due to chemical changes within the cell during storage. The degree of calendar degradation is significantly influenced by the SOC at which the battery is stored and the ambient temperature. The test results illustrate the impact of SOC and temperature on battery performance, with higher SOC and temperatures leading to more rapid capacity loss over time.

In a calendar life test, a battery cell was rested at 50% and 100% SOC (at 25 °C only) and 100% SOC (at 25 °C and 45 °C). Figure E-10 shows the capacity fade after approximately 150 days of storage. The self-discharge is expected to become more significant under more severe storage conditions such as high SOC or temperature. DNV considers the storage performance at 25 °C and 50% SOC resulting in 98.8% retention after 150 days of storage to be in line with similar products in industry.

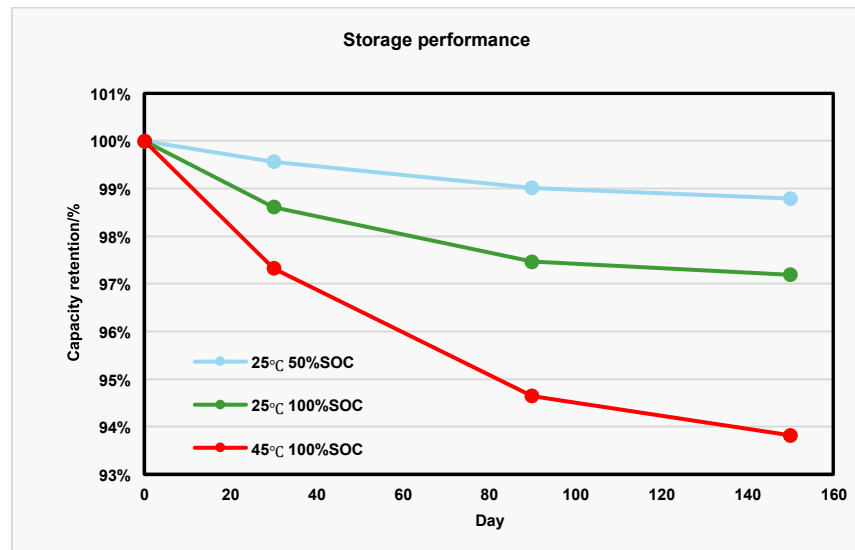


Figure E-10 Storage test (Calendar life test)

E.4 List of IEC test reports and certificates

Table E-2 displays the following additional test reports and certificates for SolaBank 3.0 BESS utilizing Sunwoda cell:

Table E-2 IEC test reports and certificates list (Sunwoda cell)

Component	Test standard	Certification/Test verified
Unit	IEC 62619	The unit model # CSI-SolBank-R-418-2h-A and CSI-SolBank-R-418-4h-A have obtained IEC 62619 certificate issued by TUV Rheinland [200] [201].
Unit	IEC 63056	The unit model # CSI-SolBank-R-418-2h-A and CSI-SolBank-R-418-4h-A have obtained IEC 63056 certificate issued by TUV Rheinland [200] [201].
Integrated BESS	IEC 62477	The BESS model # CSI-SolBank-S-5016-2h-EU and CSI-SolBank-S-5016-4h-EU (Sunwoda cell) have obtained IEC 62477 certificate issued by TUV Rheinland [202] [203].
Integrated BESS	UN 38.3	The unit model #CSI-SolBank-S-5016-2h-NA and CSI-SolBank-S-5016-4h-NA have been tested with UN38.3 requirements and test report issued by CVC Testing Technology Co., Ltd [204] [205]

E.5 UL 9540A testing

UL 9540A testing is a destructive test method used for evaluating the thermal runaway impacts in a BESS and gathering data to assist in assessing or developing mitigation measures for the failure event, propagation of the failure, or consequences of an event, such as an explosion or fire. The test, which does not have pass/fail criteria, can be performed on a cell, module, or unit level. UL 9540A is ANSI (American National Standards Institute) accredited and is currently considered to be the most appropriate published methodology to provide comprehensive, consistent, and reliable third-party data for battery failure testing. DNV notes that UL 9540A is a requirement for the UL 9540 certification mandated by code in Section 1207.11.1 of the 2024 IFC.

The following sections summarize the cell level test. DNV will update this section in subsequent revision of the Report when UL 9540A module and unit level test reports are available.

E.5.1 Cell-level results

DNV has reviewed the 4th edition of the UL 9540A cell level test report [83] bearing model number SBP-01-3140. At the cell level, the UL 9540A testing whether thermal runaway can occur in a single cell and provides insights into onset temperatures for venting and thermal runaway, gas composition and volume. To provide comparison and benchmarks, DNV has reviewed test reports for cells that were conducted under the same or similar conditions for cells with similar chemistry, capacity and form factor.

Test method and deviations: DNV notes that the cell venting and thermal runaway temperatures reported were not recorded from under the heater as required by section 7.3.1.7 of UL 9540A 4th edition test methodology. This will likely cause the reported temperatures to be lower than what has been reported for similar cells in the industry.

Venting and thermal runaway temperatures: The cell venting temperature and thermal runaway temperature were 121.0 °C and 168.5 °C, respectively. DNV notes that the cell venting and thermal runaway temperatures are lower than what DNV has typically seen for LFP battery chemistry. However, the cells displayed a difference of roughly 47 °C between the temperature at cell venting and thermal runaway. DNV views the wide cell venting and thermal runaway temperature difference as beneficial for the cell as there is more of an inherent barrier in place for increasing temperatures and may provide enough time for safety systems to detect and respond to thermal events. Additionally, DNV reviewed the BMS setting which is configured in such a way that if cell temperature exceeds 55 °C, the charging/discharging is prohibited and if cell temperature exceeds 58 °C, the BMS will disconnect the contactor within the BESS. Hence the battery will be isolated well before the cell venting temperature [88].

Gas composition and volumes: In comparison with other tests DNV has reviewed that were conducted under the same or similar conditions, the gas composition reported for the Sunwoda cell has a lower proportion of H₂. In general, however, the amount of hydrogen produced could qualitatively relate to an energetic explosion, although a detailed quantitative analysis of this data would be necessary to determine the impact. A total of 182.9 L of gas was produced during the test. Additionally, the volume of gas produced was below average on a per-Amp-hour basis. This may be a product of the form factor of the cell but would contribute favorably to the safety of the cell. Additionally, the BESS is equipped with gas detection systems, enhancing safety by identifying off-gassing and enabling early detection, which helps mitigate cell thermal events before they escalate to thermal runaway.

Performance criteria: DNV notes that the UL 9540A test method stipulates that the cell level test should meet the following two performance criteria: thermal runaway should not be induced, and off-gassing event should not produce flammable gases. Since both thermal runaway was induced and flammable gases were produced (typical for LFP cell chemistry), the cell level test did not meet the performance criteria. Hence, the battery modules utilizing this cell, shall be subjected to UL 9540A module level test.

E.5.2 Module-level results

DNV has reviewed the 4th edition of the UL 9540A module level test report [84] bearing model number CSI-SolBank-P-104.5-2h-X. The module level test provides insights into how thermal runaway propagates from a single failed cell to adjacent cells in a module. The test results help designers optimize module design and validate safety systems in the BESS.

Test method and deviations: DNV did not identify deviations from the test method described in UL 9540A 4th edition, section 8.

Observation: The test results indicated that no fire, flames, flying debris, explosive discharge, sparks, electrical arcs or re-ignitions observed. During the test, one initiating cell went under thermal runaway and propagation occurred to four additional adjacent cells.

In addition, the test report stated that 197.76 L of hydrogen, 23.30 L of carbon monoxide, 278.66 L of carbon dioxide and 228.54 L of hydrocarbons gases were generated during the test. Hydrogen and hydrocarbons, such as methane and propane, are explosive and flammable gases. In addition, carbon monoxide is an extremely flammable gas that can readily form an explosive mixture with air. Carbon dioxide is also an asphyxiant.

Performance criteria: DNV notes that the UL 9540A test method stipulates that the module level test should meet the following two performance criteria: thermal runaway should be contained within module, and off-gassing event should not produce flammable gases. Since flammable gases were produced in cell level testing, the module level test did not meet the performance criteria. Hence DNV recommends that the battery modules utilizing this cell, shall be subjected to UL 9540A unit level test

E.5.3 Unit-level results

CSI has tested their BESS Unit, bearing model number CSI-SolBank-R-418-2h-X, CSI-SolBank-R-418-4h-X, to the 4th edition of the UL 9540A test methodology. TUV Rheinland conducted the unit level test [85]. UL 9540A unit tests provide insight into thermal runaway propagation beyond the single module to affect an entire unit.

BESS unit description: UL 9540A article 9.1.2 specifies that the unit level test requires initiating an internal fire (per the module level test procedure) in one BESS unit to assess fire propagation to adjacent, representatively installed BESS units. For the purposes of the test, a Unit was considered as open rack configuration which includes 4 battery modules and 1 control unit. Figure E-11 displays the location of the initiating module during unit level testing.

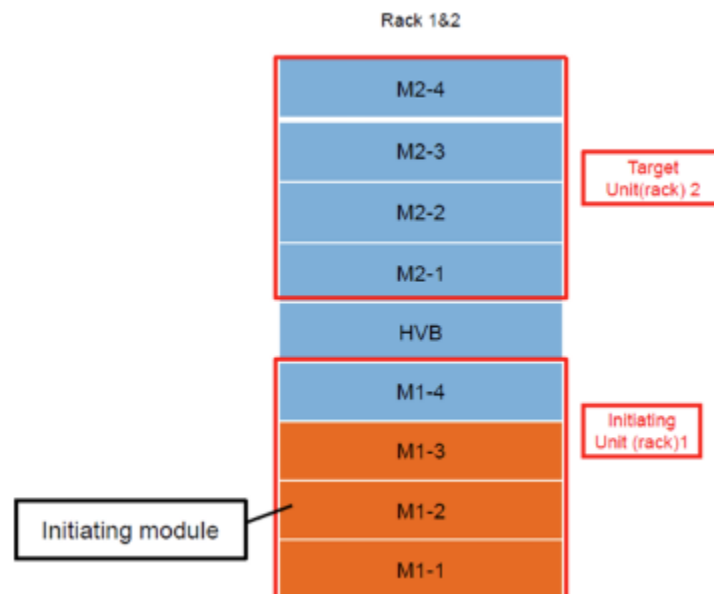


Figure E-11 Initiating module location in unit level testing

Test method and deviations: In the Unit level test, a complete BESS Unit is installed and surrounded by target (dummy) BESS and walls at the distance intended in its installation. Thermal runaway is induced in battery cells of one of the modules in the initiating BESS unit. The results are intended to report whether a fire or thermal runaway will propagate between

modules and other Units, and whether there will be flying debris or explosive discharge of gas. The 4th edition UL 9540A unit-level methodology outlines procedures for different types of installation including indoor and outdoor ground mounted systems. The test report indicates this unit has been tested for non-residential indoor floor mounted use. The text of UL 9540A allows the BESS to be tested with its integral fire protection system provided by the manufacturer in the test set up. However, no fire protection system was utilized during the test.

The following provides an overview of the test set up:

- Three instrumented walls (at least 0.61 m taller than unit height and 0.49 m extended up to exterior target unit) were constructed to form a perimeter around three sides of the initiating and target units. The walls were constructed covered with 13 mm gypsum wall board and painted flat black.
- 4 Units were used for this test (see Figure E-12 for arrangement).
- The minimum separation distance from the unit to wall and between units is displayed in Figure E-12. Customer indicated that the separation distance between the initiating unit and target unit is 601 mm [161].

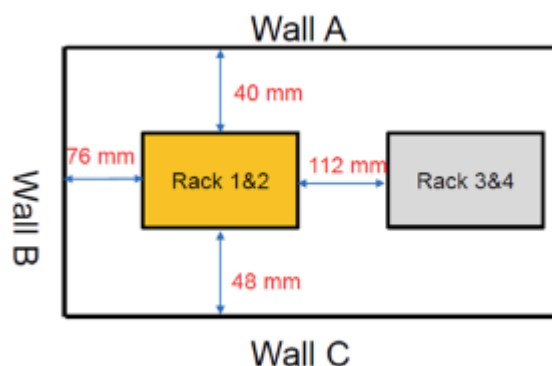


Figure E-12 Unit level test setup

Observations and performance criteria: During the tests, no flaming explosive hazards, including deflagration or detonation, were observed. Furthermore, during the test no flying debris, sparking, electrical arcs, or other electrical events occurred or were observed. One initiating cell went under thermal runaway and cell-to-cell thermal runaway propagation occurred to additional 4 adjacent cells. As stated in the test report, 276.26 L of hydrogen, 35.21 L of carbon monoxide, 365.61 L of carbon dioxide and 313.96 L of hydrocarbons gases were produced.

Table E-3 provides an overview of the performance conditions set forth by UL 9540A in addition to the summary of the Unit test observations.

Table E-3 UL 9540A Unit performance criteria for indoor floor mounted BESS

Performance condition	Test observation/remark
Flaming outside the initiating BESS unit is not observed	Meets the performance criteria. No flaming was observed internally or externally of the Unit during the test.
Surface temperatures of modules within the target units adjacent to the initiating unit do not exceed the temperature at which thermally initiated cell venting occurs, as determined in 7.3.1.8.	Meets the performance criteria. The maximum surface temperature measured on target Unit was 37.7 °C, far below the cell venting temperature of 121 °C reported in the cell-level test.

Performance condition	Test observation/remark
For units intended for installation in locations with combustible constructions, surface temperature measurements on wall surfaces do not exceed 97 °C of temperature rise above ambient temperature per 9.2.15.	Meets the performance criteria. The maximum surface temperature on the adjacent walls was 58.6 °C, below the 97 °C temperature rise performance criteria.
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.	Meets the performance criteria. Explosion hazards were not observed during the test (internal and external).
Heat flux in the center of the accessible means of egress shall not exceed 1.3 kW/m ²	Meets the performance criteria. Maximum ~0.006 kW/m ² heat flux detected on instrument wall.

While cell-to-cell propagation occurred during the test, module-to-module and unit-to-unit propagation was not observed indicating an adequate thermal barrier between modules. The Unit level results show a resiliency of the Unit to thermal runaway propagation and fire hazard in a single failure event. The unit level performance criteria have been met, therefore, the tested spacing distances can be used as the minimum spacing for the BESS installation

E.6 Explosion prevention

Methodology: The explosion/deflagration prevention system is designed to reduce the concentration of flammable gas inside the BESS enclosure below 25% LFL by means of a ventilation system. Systems that employ this methodology are required to comply with NFPA 69 design guidelines (Standard on Explosion Prevention Systems).

System description: Although the enclosure dimensions result in a total volume of 31.38 m³, subtracting out the internal components of the cabinet results in an open volume for air of 8.74 m³. The ventilation system is comprised of 2 hydrogen gas sensors and a ventilation system which includes 1 exhaust fan and 2 motorized louver intakes, as displayed in Figure 5-16. The exhaust fan is manufactured by Nanjing Heben M&E Equipment Technology Co., Model #: TPF13, TPF14; size: 410x360 mm with a rated ideal air flow capacity of 1390 m³/h (820 CFM). The report states that due to the flow restriction of the components inside the container the fan operates at 1020 m³/h (600 CFM). 1020 m³/h was the flow rate used to run the CFD calculations. DNV finds the noted reduction in flow from ideal to actual to meet expectations.

When a Level-1 gas detection alarm (concentration above 10% LEL) occurs the ventilation system opens the intake louvers and operates the exhaust fan to purge the battery cabinet with ventilation.

Design compliance: Systems that employ methodology described above are required to comply with NFPA 69 design guidelines (Standard on Explosion Prevention Systems). DNV reviewed a CFD analysis report [206] which demonstrates the deflagration prevention system's performance using NFPA 69 guidelines through a set of documented technical assumptions.

The CFD simulation was accompanied by the UL 9540A 4th edition cell, module and unit level test results of SolBank 3.0 associated with Sunwoda cell model # SBP-01-3140 which includes the flammable gas concentration, number of cell's failure and gas release rate. Based on UL 9540A test results, a total 5 cell's failure scenario resulting in a total of 92.35 LPM gas release rate was assumed in the CFD simulation. The gas release rate kept constant throughout the simulation as a conservative approach. DNV views the flow modeling decisions to follow reasonable engineering judgement.

Furthermore, 3 gas release positions are identified as at the bottom module of the left rack, middle rack, and right rack of the enclosure. DNV finds the assumptions regarding the gas release positions to be effective for the conservative analysis, as the detection location was furthest from the gas release location which introduced delay in detecting. Additionally, this setup is helpful in evaluating the performance of the fan in removing flammable gases from the bottom surfaces.

DNV notes these technical assumptions, gas release location, gas release rate and reduced air flow rate are reasonably above and beyond the scenario described in UL 9540A testing, and views them favorably.

The simulation results indicate that the ventilation system can maintain the flammable gas concentration below 25% of LFL for all 3 modeled cases and therefore meets the requirements of NFPA 69.



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