



***Distributed Energy Storage
Systems in Data Centers and the
Need for Clear and Standard
Reporting of
Diagnostics/Prognostics and
Hazard Communications***



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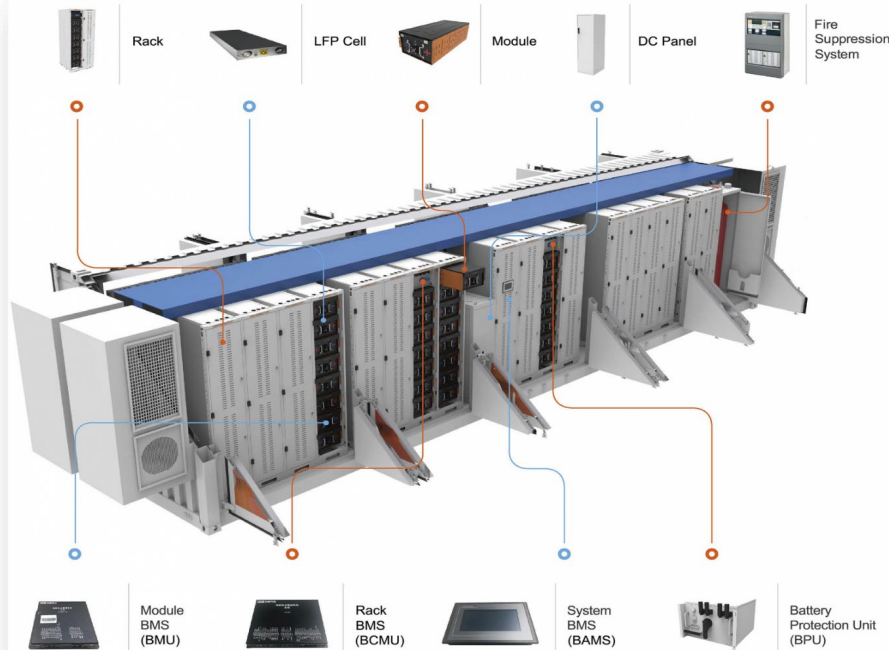
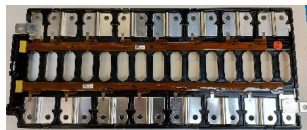
Chair, SAE Battery Standards Steering Committee
Chair, SAE J2990 First/Second Responders Task Force
Chief Safety Officer, NAATBatt
Chairman Emeritus, NAATBATT

ESS Portfolio

HV connectors & assemblies



Cell connection systems

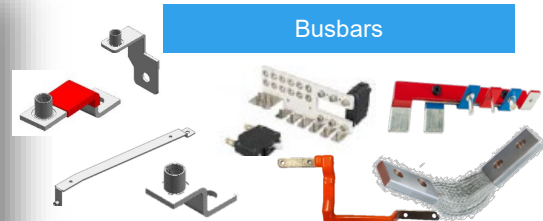


Battery Swap Modules



Blind mate

Busbars



Sensors

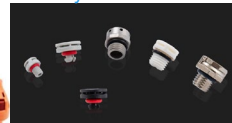


Other

Modular Battery Connections



Battery Vents



Overmolded Cables & Splices



Terminal Blocks



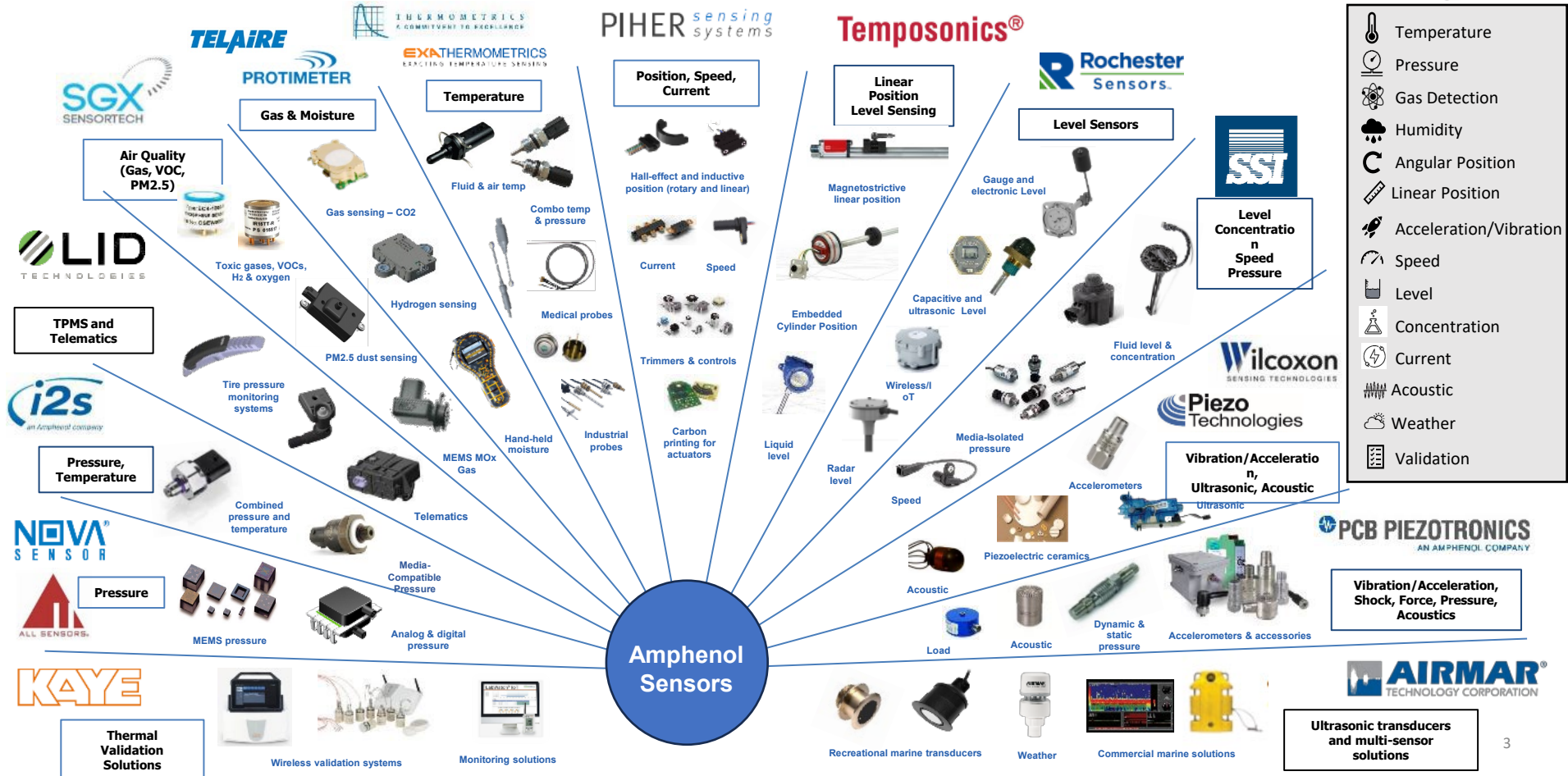
BarKlip® BK300

PwrBlade+

Amphenol Sensors

Amphenol Sensors

Delivering Value-Add Sensors



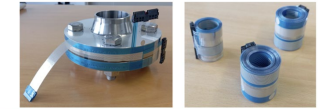
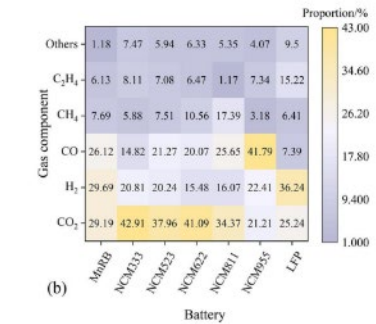
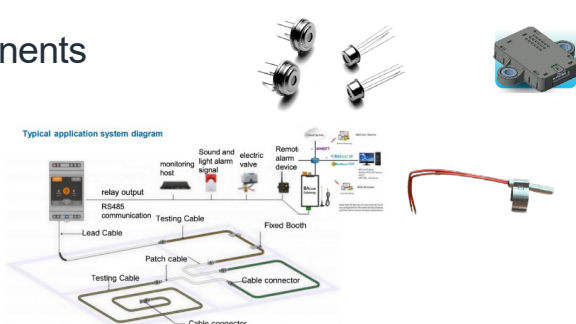
- Temperature
- Pressure
- Gas Detection
- Humidity
- Angular Position
- Linear Position
- Acceleration/Vibration
- Speed
- Level
- Concentration
- Current
- Acoustic
- Weather
- Validation

Amphenol Sensors enable latest generation BESS and Data Center capability



Enabling Sensors:

- Cell venting Detection / Thermal Runaway
 - Gases, including H₂, CO₂, CO, additional gases
 - Multiphysics combinations including gases, pressure, temperature, humidity
- Non-contact infrared sensing of high voltage components
- Coolant and refrigerant pressure and temperature
- Coolant leak and water detection
- Current sensing
- Cell connection systems



Energy Storage requires sensor control and failure detection



Rechargeable Energy Storage batteries – from a consumer convenience to a global necessity

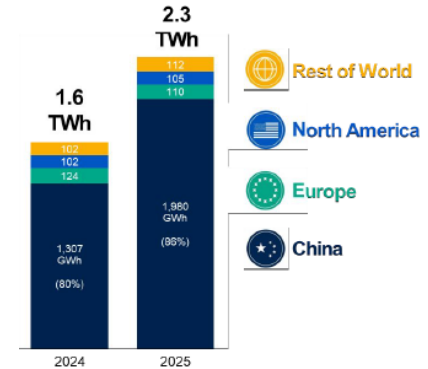


New battery systems:

- “Nine 9’s” level of quality control - over 7,000 quality inspection points
- Various chemistry combinations for electrode materials; require critical minerals
- Energy density increasing from 180 W-h/kg to >500 W-h/kg
- Increasing voltage levels: 800V and >1.5kV in HD applications, BESS, & hyperscale data centers
- Can withstand thousands of charge/discharge cycles:
 - Can outlive “first life” vehicle and serve in BESS and reman applications
 - “Swappable” packs - do not necessarily stay with vehicle or application
- Battery systems can be most expensive BOM component of vehicle and systems
- **No regulations/standards on diagnostics reporting specific across the BESS scale**
- **Faults can have benign or severe outcomes**
 - Failure modes can result in fire/explosion, even when system is “idle”
 - Failures can exhibit varying latency time between initiation and potentially catastrophic failure
 - Other failure sources (control electronics, cooling systems, water ingress) can trigger pack incidents.

Battery Current, Voltage, and Temperature sensing are no longer adequate measurements for safety

Battery system design is a tradeoff between energy density, safety, and cost



In 2025, global lithium-ion battery cell production surpassed

2.3 TWh

65% were LFP batteries

1/5 were ESS batteries

86% were made in China

Source: Data provided by CRU Group

Battery Failure and the need for improved passive and active controls

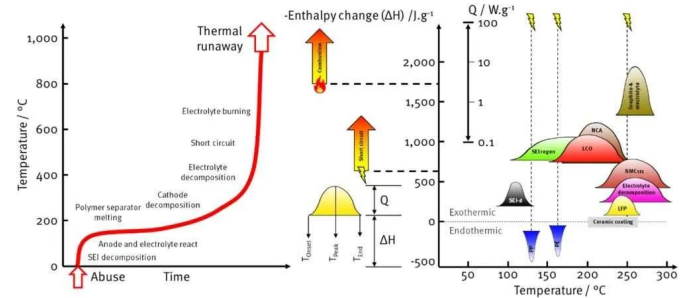
Cell failure is a complex physics phenomenon and should not be over-simplified

Considerations:

- Risk of thermobaric detonation /deflagration / fire
- Electrolysis of water vapor **inside the cell!**
- Plume is highly conductive – **arc flash**
- Ultrafine metal particles – thermite rx
- Flammable electrolyte release
- Release of hydrogen
- Asphyxiants including HF, and Na+ cells release HCN
- Latent effects include corrosion/failure of electronics
- Even solid-state cells can release hydrogen from binder

*Cell venting failure is NOT benign and must be detected!
Safety & robustness knowledge is evolving field*

Typical model does not account for all physics behavior



Arc flash damage in hEV pack from vented cell



Safety issues make headlines and headwinds to the industry – examples:



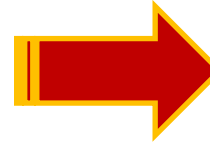
Production Facility incidents

- Taiwan- TCC/Molicell – 15 injuries
- Korea - Aricell – 22 deaths



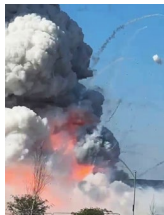
Transportation incidents

- Delphine RoRo and 5 other sinkings
- EV Battery pack in trailer in TX, Mar 2023
- Birmingham, Alabama & Georgia



Application incidents

- New York City: e-bike fire – 4 deaths
- California – 3 deaths
- Korea – charging fire



Recycling incidents

- France – evacuation / facility loss
- Scotland – evacuation / facility loss

EV Ocean transport bans/restrictions

BANS		
Shipper	Category	Note
Matson	Ban	Ban on EVs/Hybrids.
Alaska Marine	Ban	Ban on EVs/Hybrids.
USC	Ban	Ban on EVs/Hybrids.
Havila Kystruten	Ban	Ban on EVs/Hybrids (Norway ferry operator).

RESTRICTIONS		
Shipper	Category	Note
Royal Shipping Lines	Restriction	No RoRo shipment of EVs, allowed only in sealed containers.
Troy Full Shipping (NZ)	Restriction	Only Nissan Leaf accepted; other used BEVs excluded.
Mitsui OSK	Restriction	Evidence of sleeping back from used BEV transport, scope unclear – monitor.
European Ferry Operators (Grimaldi, BC Ferries, etc.)	Restriction	SOC caps (e.g., 40%); no damaged/irreparable EVs accepted.

LIMITATIONS		
Shipper	Category	Note
Maersk	Limitations	EVs/BEVs must be declared as Dangerous Goods (IAD1156A/IAD1171). Strict documentation and handling rules.
OMA CGM	Limitations	Damaged EVs prohibited. Restrictions on older batteries. State of Charge limits (<30%) and controlled storage required.
Hapag-Lloyd	Limitations	EVs subject to Dangerous Goods restrictions. Restricted commodities list may block certain vehicles.
Stena Line	Limitations	No onboard charging on most vessels. Damaged EVs refused. Limited acceptance. Inspection required.
DFDS (Brittany Ferries)	Limitations	Ban/restrict onboard charging. EV acceptance subject to inspection and battery condition.
Ro-Ro & Car Carriers (general)	Limitations	Class 9 Dangerous Goods declaration often required unless IMDG SP961 applies. Damaged EVs refused. Soc ~30-40%.

Fears of massive battery fires spark local opposition to energy storage projects

Even though incident level is low, outcomes can be unexpected, severe and long duration

Incidents- Large Scale Energy Storage



Overall number of incidents appears to have decreased, but incident scale has involved much larger systems (like Moss Landing)

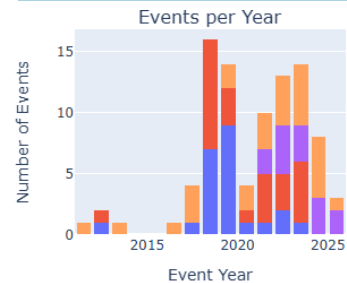
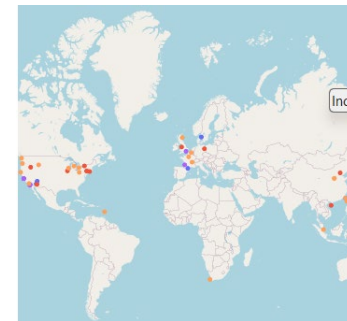
- Incidents at BESS, substation, EV Charging and Data Centers
- New BESS facilities are largely LFP chemistry

Recent Standards Changes:

- **UL 9540A:** Test Method for Battery Energy Storage Systems (BESS >20kWh)
 - more stringent gas and temperature testing in 2025 updates
- **NFPA 855:** Standard for the Installation of Stationary Energy Storage Systems (2026)
 - Stricter installation rules limiting total stored energy
 - 10kWh/dwelling, 1kWh for portable
 - Specific protection required for indoor spaces
- **In Development: NFPA800**

2025 showed improvement in incident levels

Location	Energy (MWh)	Power (MW)	Module Type	Application	Installation	Event Date
US, CA, San Marcos			Li ion	EV charging	Parking lot	21 January 2025
US, NY, Warwick	17.9	4	Li ion	Peak shaving		10 December 2025
US, AZ, Peoria	100	25	Li ion	Peak shaving	Substation	1 October 2025
US, NV, Boulder City	360	80	Li ion	Solar shifting	Solar + storage	23 September 2025
US, CA, Piedmont	240	60	HMC	Solar integration	Solar + storage	30 August 2025
Netherlands, Almelo					Commercial	4 August 2025
South Korea, Gyeonggi-do, Songdo-dong				Industrial	Indoor	16 June 2025
South Korea, Gyeonggi-do, Pohang City			Li ion	Industrial	Building	16 June 2025
US, OR, Hillsboro				Data center	Data center	22 May 2025
England, Gloucestershire, Cransford	51	10	Li ion	Solar shifting	Solar + storage	28 March 2025
England, Essex, Tibury	600	300		Frequency Regulation, Capacity Market, Balancing Mechanism, Wholesale Power Markets	Substation	19 February 2025
US, CA, Moss Landing	1,200	300	Li Energy Solution (HMC)	Resource Adequacy	Power Plant	16 January 2025
Spain, Valencia, Port of Gandia		1	Li ion	Port	Solar + storage	5 January 2025
South Africa, Tloane Mountain				Backup energy resource	Indoor	25 October 2024
Canada, ON, Bradford				Peak Shaving	Commercial	12 September 2024
Singapore				UPS	Data center	10 September 2024
US, CA, Escondido	120	30			Substation	5 September 2024
US, CA, Santa Ana				Industrial		17 July 2024
USA, CA, San Diego	250	200	Li Chem	Energy shifting		10 May 2024
US, CA, Kearny Mesa	80	20	LFP		Substation	29 April 2024
Japan, Kagoshima, Ito				Solar integration		27 March 2024
Taiwan, Lanyu	1.1				Power Plant	28 December 2023
USA, ID, Malba	8	2	Powin Energy	Distribution Resource	Substation	7 October 2023
France, Martinique, Saint-Espirit				Solar integration	Farm	20 September 2023
Australia, Queensland, Boultoncombe	100	50	Tesla		Substation	26 September 2023



System Size ■ < 5MWh ■ 5 - 50 MWh ■ 50 MWh < ■ Unknown

https://storagewiki.epri.com/index.php/BESS_Failure_Incident_Database



Large Scale Fire Testing (LSFT) Became an Established Testing Requirement in 2025

A change in the **2026 Edition of NFPA 855**¹ supplanted **Edition 5 of UL 9540A as the de-facto Large Scale Fire Test**. However, consensus was reached in August of 2025 on a new revision that will bring the UL 9540A test method back into alignment with the intent of NFPA 855 and the model fire codes that reference it.²

Standard	Focus	What	Why
UL 9540A Ed. 5 [Edition 6 publication target March 31, 2026]	Thermal runaway behavior, fire and gas hazards, module/unit propagation	Internal propagation, gas composition, ignition susceptibility, flame/heat characteristics	To understand internal failure mechanics and gas hazards. ³ Consensus revisions provide data required to determine separation distances, suppression design, and installation safety
Large Scale Fire Testing (per 2026 NFPA 855, no specific standard referenced)	Fully developed unit-level fire + external exposure risk.	Real-world fire spread, heat flux to exposures, suppression performance, structural risks	Required to determine separation distances, suppression design, and installation safety ⁴
UL 9540B Outline of Investigation	Residential ESS fire propagation	Fire severity and spread from a failure of an ESS in a residential setting.	Addresses risk to occupants by evaluating the "fire propagation characteristics of residential BESS" ⁵
CSA C800 {Note: CSA TS 800 interim specification now incorporated into this document.}	Reliability & QA	ESS reliability under extreme external abuse conditions	Establishes BESS behavior when subjected to abuse resulting in a developed fire condition. ⁶ Developed to supplement UL 9540A Edition 5.

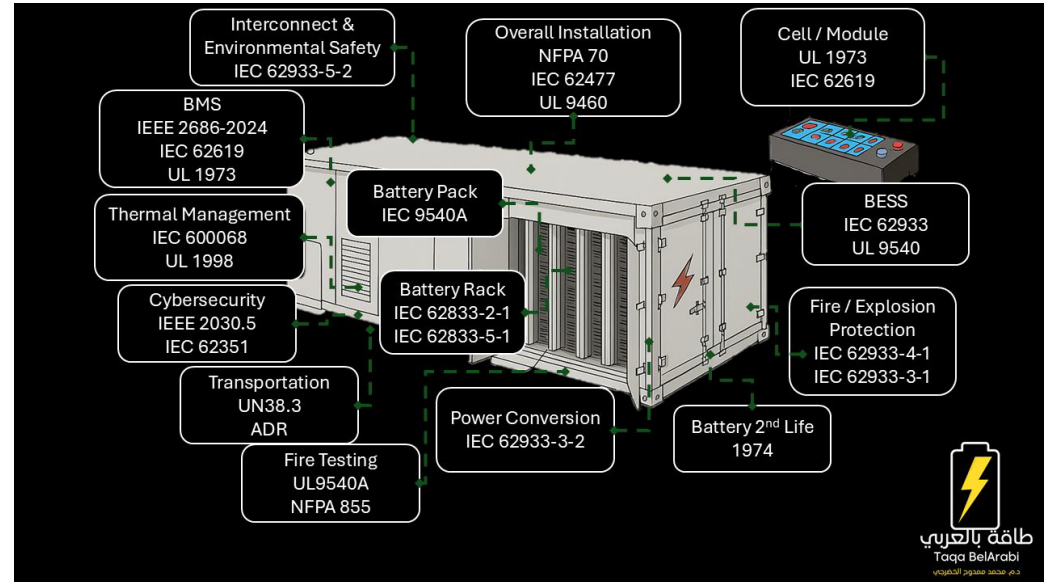


Source: [NFPA Standards Council Decision](#), [UL Standards Activity](#), [UL 9540A, Edition 5, See Scope](#), [NFPA Int'l](#), [UL 9540B, See Scope](#), [CSA Group](#)

Evolving BESS Regulations & Standards



	BESS Highlighted New Standards [2025]
NFPA	NFPA 855: 2026 edition (released 2025)
GB	GB 44240-2024 (effective Aug 1, 2025) GB 38031-2025 (effective Jul 1, 2026)
IEC / ISO	IEC 62933-5-2:2025 IEC 62933-4-3:2025 IEC 62933-4-2:2025 ISO 23625:2025
UL	UL 9540 (Edition 3, 2025) UL 9540A (5th Edition, 2025) UL 9540B (Outline of Investigation, 2025)
IEEE	IEEE 2686-2024 (published Feb 7, 2025) IEEE 2993-2025
CEN / CENELEC	EN 18061:2025
SAE	SAE J3327_202509 (2025) SAE J2929 SAE J2464 SAE AS6413 / SAE AIR6840
Codes & local requirements	California Energy Code 2025 (Nonresidential)
IOGP - specifications for Oil/Gas industry	IOGP S-753 and IOGP S-753Q (Jan 2025, public review)



Note: Standards shown are selected from Taqa BelArabi standards Database based on multiple sources: IEC, IEEE, UN, UL, GB, ISO, & NFPA.

**BESS Standards are rapidly evolving to address safety concerns
Regulations are regional and references to standards vary significantly**





Regulation:

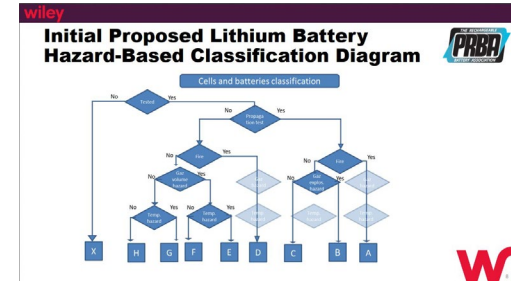
UN 38.3 Transportation of Li-ion Batteries

- UN3480 (Li-ion cells); UN3481 (Li-ion batteries contained in equipment)
- Expect incremental clarifications via Amendment and proposals from 2025 with more restrictive air rules (IATA/ICAO)
- 2026: SoC controls (30% SOC for transport)
- New categorization of battery cells and packs hazard level in UN38.3 will be proposed 2029/2030, involving new testing requirements on cell and packs



Standards:

- NFPA800 – Battery Safety Code (2026 Draft under review)
- J2950 Recommended Practices for Shipping Transport and Handling of Automotive-Type Battery System - Lithium Ion (under revision)
- J3303_202510 - Lithium and Lithium-Ion Cell and Battery Containment Performance Recommended Practice
- J3235_202303 - Best Practices for Storage of Lithium-Ion Batteries

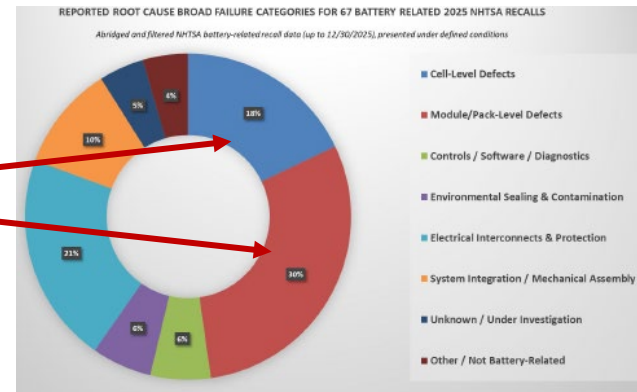


Battery transport issues and gaps to be addressed



Transportation:

- Significant issues exist in transporting End of Life (EOL) and Damaged/Defective/Recall) large format systems both on land and by sea
 - Still significant number of recalls, many for cell & pack defects
 - EOL /DDR packs currently stranded on many island nations due to lack of appropriate containment technology in event of catastrophic event on vessel
 - Over-road transport of BESS systems requires specialized transport due to mass and center of gravity
 - Shippers have not followed manufacturer's recommendations
 - Many shippers now requiring 30% SOC in application
 - Difficult to correlate voltage or "EV range" to "Pack SOC"



Actions:

- Improved recommendations/guidance
- New developments in large format containment system for improved thermal/fire management and detection/notification of incidents in transport
- SAE Decommissioning/Discharge Committee activities and related research

BESS in Data Centers is a distributed network of batteries



In-Rack



In-rack batteries **protect the highest-value compute closest to the load**, helping reduce transfer issues and supporting fast-response power needs inside the white space. The opportunity is strongest where **uptime and rack-level resiliency matter most**, though rising AI rack densities may push some deployments toward separate battery racks rather than true in-rack designs.

UPS



Modular or cabinet UPS is the **most established battery opportunity** because it delivers the core **3–5 minute ride-through** needed to bridge utility loss until generators start. Growth remains strong, but the key challenge is **packing more backup power into fewer cabinets** as data center MW blocks get larger.

Grid Storage



Grid storage is the **biggest emerging opportunity at the site level** because it can support **peak shaving, load smoothing, and power capacity constraints** tied to hyperscale and AI buildouts. Its role is highly site dependent, but interviews suggest ESS becomes much more attractive where **grid access is tight** or where operators are pairing storage with gas, renewables, or other on-site power strategies.

Safety from Prevention to Containment

Structural Safety Considerations

Design choices to prevent propagation of events

Design considerations includes pack level choices, integration of systems, material selection, and incorporation of engineering controls.

Example of standards that guide considerations:

- UL 9540
- NFPA 855
- NFPA 68/69

[Source \[1\]](#)

Thermal Management Systems (TMS)

Maintains temperature "homeostasis"

System consists of: Sensors, set point management, cooling apparatus.

Types of cooling:

- Immersion cooling- pack submerged in dielectric liquid
- Liquid cooling- circulating liquid to absorb heat
- Air cooling- fans and blowers force circulated air

[Source \[2\]](#)

Fault Detection and Alarms System

Detects/diagnoses stages of a thermal runaway cascade

System consists of mixture of sensors and alarms/alerts

Types of sensors:

- Gas detection- vent gases
- Thermal detection- temperature anomalies at cell/module/pack
- Voltage imbalance monitoring- flags cells/modules/packs for potential faults

[Source \[3\]](#)

Active Fire Suppression System (FSS)

Reacts to extinguish fires of the system

System consists of automated response that triggers fire suppression agents

Types of suppression:

- Gas based suppression- inert or extinguishing gases
- Aerosol suppression- fine particles to interrupt combustion
- Water-based suppression- water to extinguish fire

[Source \[4\]](#)

Prevention

Containment

When designing a battery system, several system-level strategies exist to ensure proper safety against thermal runaway events.

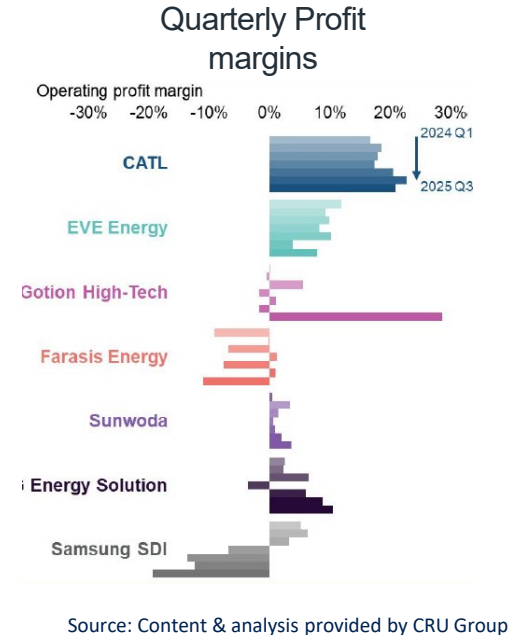
Balancing Cost, Utility, and Safety to become profitable



Battery Production

To be competitive, cell manufacturers need extreme (& expensive) scale

- Long payback periods and finances:
 - Pack prices below \$100/kW-h, BESS below \$70/kW-h
 - Best-in-class operating margins ~25%, with many competitors at negative operating margin in 2025
 - Raw material price volatility, tariffs, lead to financial uncertainty
 - Pack-only assemblers struggle with “single-digit” margins
 - Vertical integration from raw material to application improves cost controls
 - Liability/recall insurance increasing drag on margins
- Safety risk drives exceedingly tight quality controls
 - Cell manufacturing can include ~7000 quality checkpoints from raw material to final product
 - Extreme levels of automation and quality data collection, AI analysis required
 - Traceability links raw material sourcing, process control information to every single unit produced
 - Typical yield loss at formation/aging can be up to 10%



Application demands drive design constraints, the push for increasing utility must be balanced with safety and cost

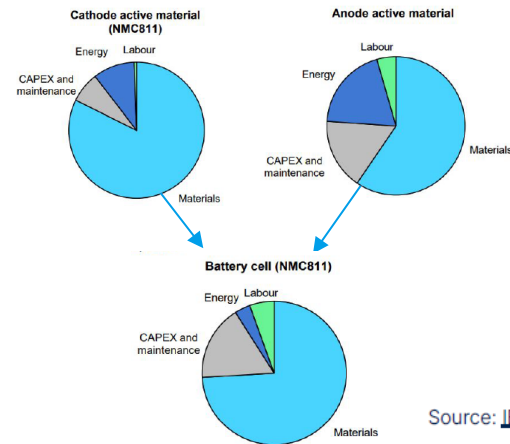
Batteries...the balance sheet



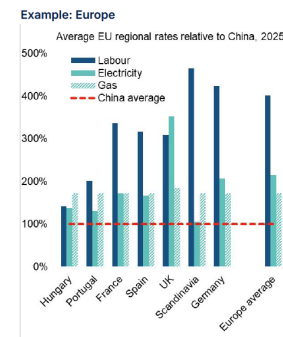
Battery Production – operational challenges

- Regardless of chemistry, material dominates cost structure
- Material price volatility and availability: ~60-80% of operating costs
- Manufacturing location can have significant impact on profitability
 - Labor costs in EU 400% higher than China
 - Electricity costs in EU 200% higher than China
 - Natural gas prices in EU 60-70% higher than China
- Cell chemistry and package design drive fundamental manufacturing processes and are not easily changed within facility
 - Cathode chemistry (LFP, NMC, Na+, LTO, etc)
 - Package design (Prismatic, Pouch, cylindrical)
 - Package size (from a few A-h up to 1,000 A-h)
- While somewhat flexible, Manufacturing line setup driven by target application market
 - BESS, consumer product, medical, drone, eVTOL, robotics all drive unique energy, power density, performance requirements

Manufacturing facility, equipment, tooling, and even logistics must follow a business plan with high confidence target market/customer/demand



Source: [IEA](#).



Source: [1] [CRU Group](#)

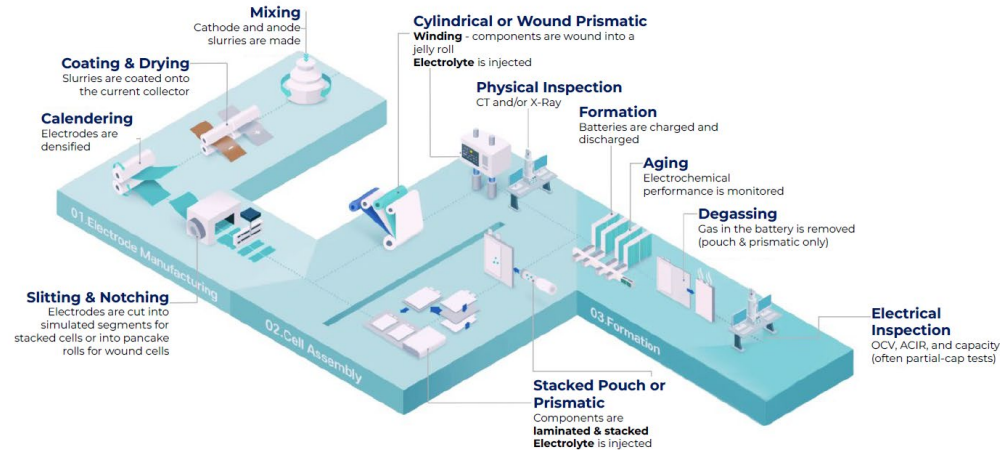
Process Flows and Yield



“Typical” Battery line

- CAPEX Tooling: \$55 to 150 million/GWh
- Qualification of supplied product starts with materials on pilot line (1,000’s of cells)
- Line qualification includes:
 - Qualification of quality control processes
 - Cycling Testing
 - Destructive/non-destructive quality checks
 - Abuse testing
 - Early samples to customers (battery-pack-OEM DV/PV)
 - Qualifying a line can be a multi-year process
 - Failure can delay SOP by many months

Manufacturing Process Map - Overview



Graphics courtesy of LG Energy Solution.

Global competition forces competitors to scale fast or risk customer loss

Electrode Production Challenges



Challenges

dispersion uniformity;
viscosity consistency;
reaction time of mixing
team to batch variation

MIXING

Slurries are formed from active material, binder, solvent, and additives that improve dispersion and viscosity control. **Mixing order, speed, tooling, and material variability** all affect the final slurry and may require recipe adjustments to hit viscosity specs.

Challenges

wrinkling/elongation of
substrate & cracks/tears
of electrode from
thickness variation;
managing target density;
electrode waste

CALENDARING

Electrodes are **densified to a target value**. Thickness is verified here, but primary quality screening occurs during slitting.

30-50%

of total
manufacturing cost

60-100
m/min

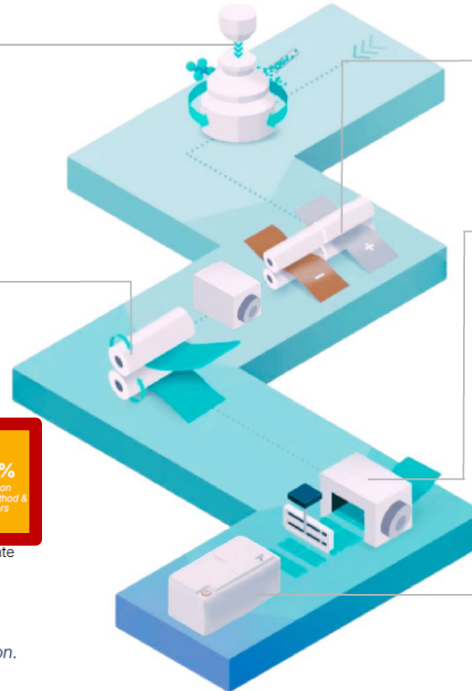
pouch film
speed

20-60
m/min
depending on
patch design

cylindrical
(pattern coating)
film speed

2-10%
depending on
calculation method &
other factors

scrap rate



COATING & DRYING

Slurry is coated onto the current collector (~54% of electrode cost). Operators must **continuously adjust** pump speed, die gap, and die-tip settings as slurry **viscosity varies** with temperature and batch changes. In-line gauges enable tight control, but **poor reactions** lead to foil breaks and long oven/die-head downtime.

Challenges

electrode uniformity;
processing time; utilization
loss (lengthy oven cool down
& heat up cycles due to
broken foil pieces);
Finally, **operator training
and reaction time** to all
these issues

SLITTING & NOTCHING

Electrodes are cut into singulated segments or pancake rolls. Uncoated areas are **cut out** leaving the parts where tabs will be grounded. **Detection & marking** of electrode defects occurs here. For **contamination**: must contain proper brush clearance & vacuum systems.

Challenges

edge quality due to blade
edge wear (burrs are
dangerous), difficult to
inspect at speed; tool wear;
**lowest OEE of any process
due to lengthy marking
process; contamination**

VACUUM DRYING

Removes **residual water** that would react with electrolyte and cause HF / swelling. Not needed when electrodes are made in dry rooms.

Challenges

processing time; large
footprint; mostly batch;
*usually Karl Fischer titration
is used for water-content
checks*

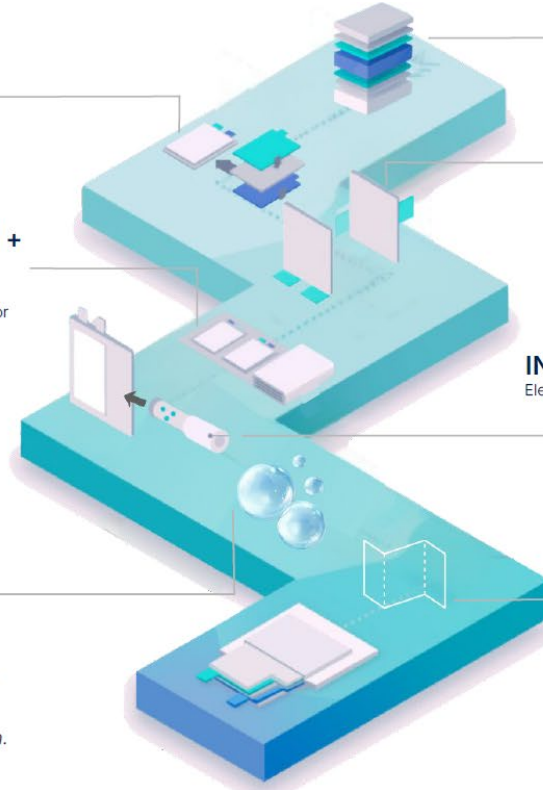
*Graphics courtesy of LG Energy Solution. Reproduced with permission.

Source: [LG Energy](#), [BCG](#), internal expertise

BATTERY REPORT 2025 |

Materials moving to extremely tight tolerance grain size, morphology, metrology, rheology

Pouch Cell Production Challenges



Challenges
electrode alignment;
balancing speed and
accuracy

LAMINATION & STACKING

Stacking notched anode & cathode sheets with separator between.
(Some lines heat-press layers after stacking.)

Minor Challenges
sealing around tabs;
overheating can cause
pouch leaks

INSERT STACK INTO POUCH + INITIAL SEALING

Stack is placed inside the formed pouch.
Three edges are heat-sealed, leaving one open for electrolyte injection.

15-35%

of total
manufacturing cost

2-20
parts/min

speed

3-5%

scrap rate

Challenges
maintaining a clean edge
for sealing cell after
degassing

FORMATION → VACUUM DEGASSING → FINAL SEAL

During formation, gas collects in the gas pocket.
After formation, the pocket is cut open, the cell is vacuum-degassed, and sealed.

POUCH FORMING

Forming the pouch cavity from laminate using a draw-form press.

Challenges
corner cracking

TAB WELDING

Ultrasonic welding of electrode tabs and attaching tab extensions.
Tabs are wrapped with insulating tape to stay isolated from aluminum pouch.

Challenges
foil damage; coating
adhesion/cohesion

ELECTROLYTE INJECTION + TEMP. SEAL

Electrolyte is metered into the pouch through the open edge, then sealed.

Challenges
dosing & distribution
accuracy; no electrolyte
residue in sealing area;
temp. seal integrity

FINAL EDGE FOLDING

Pouch edges are folded to create a compact cell.
These folds help slow moisture ingress.

Challenges
damaging cell corners

*Graphics courtesy of LG Energy Solution. Reproduced with permission.

Source: [LG Energy](#), [BCG](#), [RWTH PFM](#), internal expertise

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Bent tabs, edges, contamination, electrolyte absorption degassing, and sealing contribute to yield loss

Cylindrical Cell Production Challenges



Challenges
metal contamination;
jelly roll fit

2. TAB SHAPING & CANNING

The jelly roll is put in the cylindrical can and then fixed through welding (resistance or laser). High-speed mechanical deformation process (beading).
SPEED: 300-600 parts/min

Minor Challenge
missing or multiple
insulators

3. INSULATOR PLACEMENT

Insulator is punched and placed onto cell opening.

Challenge
false positives

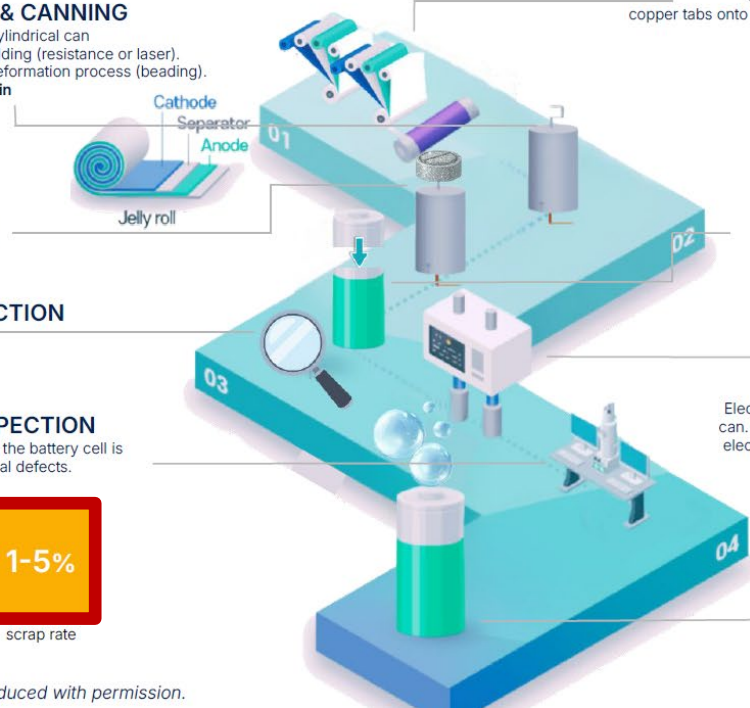
5. HI-POT INSPECTION

Internal short check

Challenge
speed of analysis
doesn't allow real-time
analysis

7. PHYSICAL INSPECTION

Through CT and/or X-Ray, the battery cell is analyzed to detect potential defects.



1. WINDING & TAB WELDING

Winding the cathode, anode, and two separator rolls. Ultrasonic welding the aluminum and copper tabs onto the cathode and anode respectively.
SPEED: 30 parts/min

Challenges
anode, cathode, separator
alignment; tabbing, taping,
cutting accuracy; tab welding
quality (can introduce safety
issues)

Note on tabless cells
There is no tab welding step. Instead, there are folded (notched) aluminum or copper ends.
SPEED: 30-60 parts/min (depending on jelly roll size)

4. TOP CAP WELDING

Top cap is laser welded onto cathode tab.

Challenges
weld spatter; weld quality

Challenges
electrolyte absorption due to
density; pooling of
electrolyte; scratching and
contamination (during
crimping)

Challenges
exhaust gas treatment (for
open pre-charge);
avoiding residual gas during
sealing and folding steps

6. ELECTROLYTE INJECTION + SEALED

Electrolyte is injected into the vacuumed can. The can is pressurized to accelerate electrolyte absorption and then crimped, final height sizing.

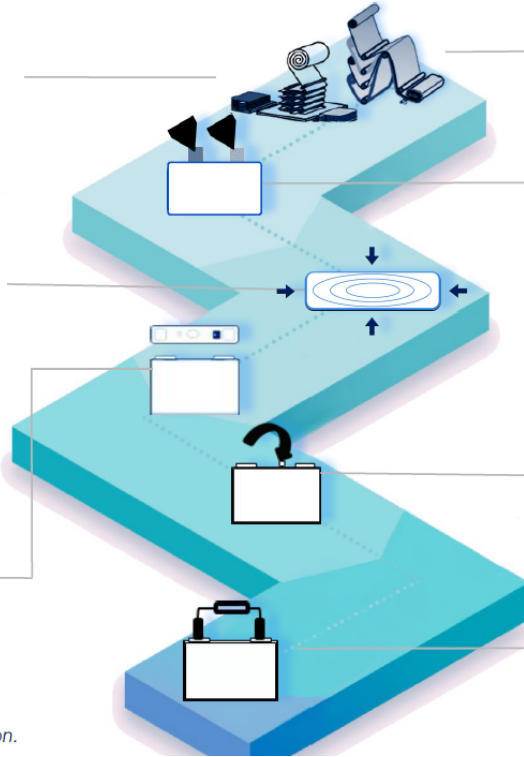
8. DEGASSING/ PRE-CHARGE

Optional process to remove gas

*Graphics courtesy of LG Energy Solution. Reproduced with permission.

Alignment, welding, contamination, electrolyte absorption contribute to yield loss

Prismatic Cell Production Challenges



Challenges
anode, cathode, separator alignment

Z-STACKING
Stacking the cathode, anode, and two separator rolls. Welding the aluminum and copper tabs onto the cathode and anode respectively.
SPEED: 5-15 parts/min

Challenges
throughput

HOT PRESS
The hot press machine works on the principle of heat and pressure application to achieve a strong and reliable bond between battery components.
SPEED (DWELL TIME): >10 seconds/unit

10-20%
of total manufacturing cost

4-6%
scrap rate

Challenges
cap to can alignment, missed laser welding spot; pinholes (leak)

CAP TO CAN WELDING
The can to cap spot welding by laser source and followed by complete laser welding of the cap to can

WOUND PRISMATIC
Wind the slitted cathode, anode, and separator together by controlling speed, tension, etc. to create one or more jelly rolls.
SPEED: (consumer electronics) 30 parts/min; (EV) 10 parts/min

Challenges
uneven stress, burr issues, and powder loss; coating cracking

PRE WELDING & TRIMMING
The cathode and anode tab are aligned and U/S welded
SPEED: 18-20 parts/min

Challenges
anode, and cathode tab alignment

ELECTROLYTE INJECTION
Electrolyte is injected into the vacuumed can. The can is pressurized to accelerate electrolyte absorption and then sealed

Challenges
electrolyte absorption due to density; pooling of electrolyte

PRE CHARGE & FORMATION
After the filling pre charge is performed and cell is kept for RT aging and followed by formation & grading process.
Note Large cells require open formation and second fill step

Challenges
throughput

Graphics courtesy of LG Energy Solution. Reproduced with permission.

Alignment, welding, contamination, electrolyte absorption contribute to yield loss

Formation Challenges



Challenges

slow throughput due to long time required; fire (most factory fires occur here)

FORMATION

Electrochemical activation. SEI is formed on the anode

30-50%

of total manufacturing cost

5-25 days

time

2-10%

scrap rate

Challenges

residual gas inside the cell; seal quality; throughput (a lot of additional CAPEX due to dry room requirement)

DEGASSING

Pouch & prismatic only. Gases formed during aging are cut off inside of a vacuum chamber (sacrificial gas bag).

Typically in pouch, this is the final step. In some large cells, a secondary fill and subsequent charge is performed.

CHARGING, DISCHARGING/ CAPACITY CHECK

Challenges

throughput; footprint

QUALITY CONTROL

End of line check - capacity, resistance, voltage, etc., + cosmetic

Challenges

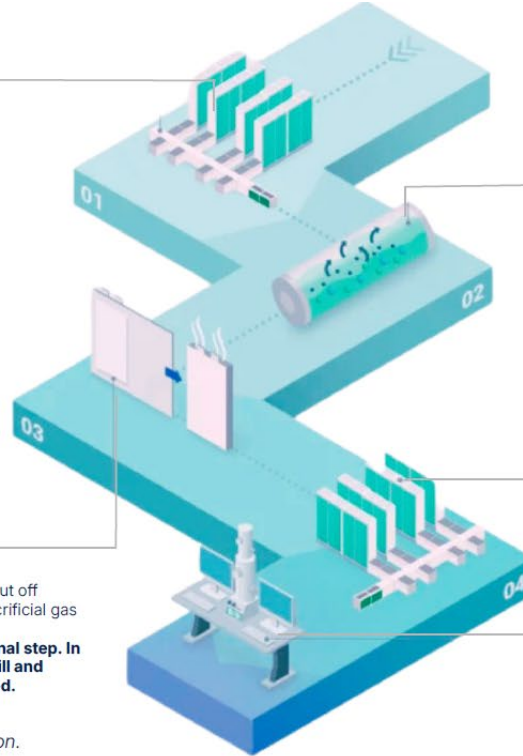
cosmetic & variation in capacity; yield

AGING

Battery is stored at a consistent temperature and humidity to allow for corrosion mechanisms from potential contamination

Challenges

process time/throughput; factory footprint; quality escapes



*Graphics courtesy of LG Energy Solution. Reproduced with permission.

Residual gas, seal quality, failure to meet quality controls during aging, charging/discharging contribute to yield loss

Pack Assembly Challenges



Challenges

surface cleaning;
cell-to-current collector bond
quality; cell matching

CONNECTING BATTERY CELLS

Battery cells are placed into the module arrangement and connected to current collectors after surface cleaning

Challenges

damage due to placement (primarily pouch); large machinery required due to module mass & dimensions; avoiding cell damage during assembly; safety at high voltages

PACK ASSEMBLY

The modules are put in the battery pack and connected, including voltage sense and thermal connections

Design Challenges

- i. Ensuring low resistance connections between modules and other connections to prevent fire
- ii. Maintaining creepage and clearance distances for high voltage elements
- iii. Preventing arcing due to contact with metallic objects during assembly

MODULARIZATION

The cells are attached to the module case, before or after connection to current collectors

Challenges

ensuring cable flexibility;
avoiding cell damage during handling

APPLYING BMS

A Battery Management System is applied to battery pack; modules typically interface with the pack BMS

CHALLENGES

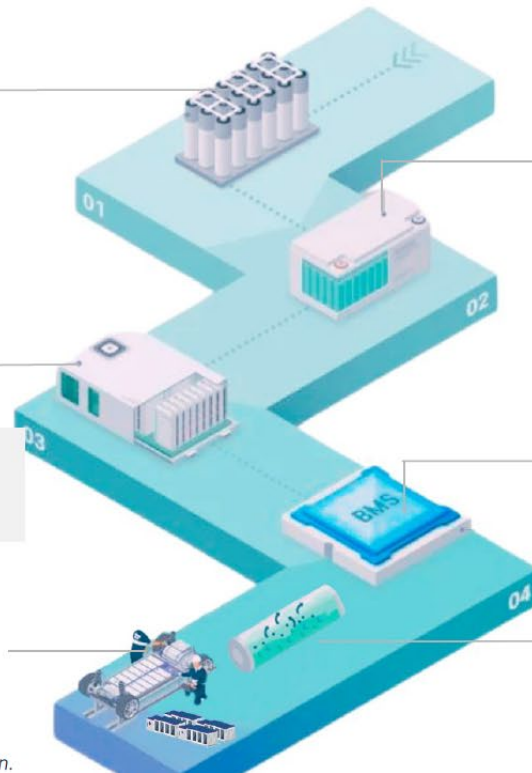
difficult & time consuming to test in a high-throughput environment

FINAL INTEGRATION

The battery packs are then used in Electrical Vehicle (EV) and Battery Energy Storage System (BESS)

FINAL TEST

A series of electrical tests are performed to ensure the highest quality, including verification of cell connections, isolation, and BMS function



*Graphics courtesy of LG Energy Solution. Reproduced with permission.

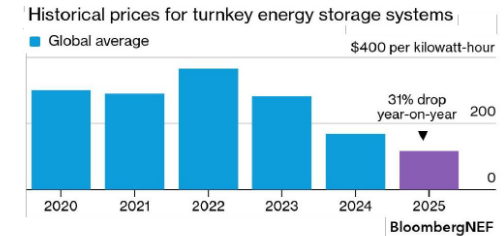
Cell matching, placement control, welding, contribute to yield loss – even low yield loss is costly!

The BESS BOM Example

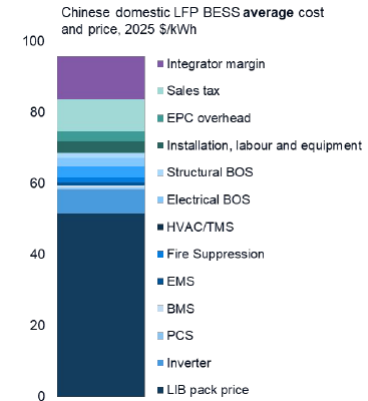


BESS installation demand increasing, but

- BESS market pricing dropped 31% in 2025
- 2025 Pricing provided 3x capacity for same price in 2022
- 50% of cost is in cells; therefore, manufacturers driving much larger cell sizes
 - LFP dominates market at >95%
 - Cells growing from 300A-h to 2000A-h
 - Na+ entering due to lower costs
 - **Yield levels 90%, what gets through?**
- Containers at maximum legal transport weights
- Stackable containers
- High automation manufacturing



Turnkey defined as the DC battery (rack and balance of system), PCS, EMS, transformer, expenses, system integrator margin, & warranty.

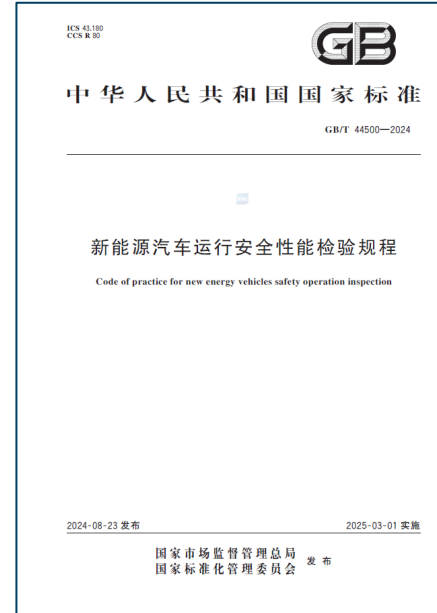


Data center and grid demands create opportunities for LFP and Na+ growth, cell cost dominates BOM

China Regulations regarding diagnostics

China Regulations governing OBD:

- GB/T 32960.3: (NEV remote monitoring/telematics reporting) defines a fairly common set of battery-related alarm/fault fields (e.g., high temperature, cell over/under-voltage, consistency issues, insulation alarm, HV interlock status) and includes an alarm level concept—though it's mainly aimed at platform reporting.
- GB/T 34590 (China-aligned ISO 26262): provides the HARA/ASIL functional safety framework that supports the “hazard-based prioritization” idea, but it doesn't define an OBD-style diagnostic communications layer
- GB/T 44500-2024: Code of practice for new energy vehicles safety operation inspection
- T/CAEE (2026 Draft): Power battery thermal runaway monitoring sensors and modules



Critical pack diagnostics + hazard ranking + standardized consumer/service messaging—is needed in China

Needs and next steps:

Various Global Regulations already require static and dynamic data reporting:

- Evaluate current “Best Practices” in battery dx
- Propose voluntary global framework for voluntary reporting “safety critical” battery and HV system diagnostics
- Common terminology and communications
- Identification of High Hazard faults (those which could lead to significant outcomes)
 - Utilize existing tools like ISO 26262 to evaluate hazard
- Controlled & Compartmentalized reporting
 - Vehicle communicates critical diagnostics to appropriate user in clear language:
 - Examples:
 - Cell venting/ Thermal Runaway
 - Over temperature
 - Isolation faults
 - Overvoltage / Overcharge / Undevoltage
 - HV interlock status/faults
- Data must be compartmentalized with strong cybersecurity measures (OEM/ transporters/owner/repair/second use/dismantler/recycler)
 - Scenarios where automated reporting of critical failures may be needed:
 - Before boarding vessel, rail, or road transportation
 - Storage / service
 - Emergency/damage incidents
 - During bidirectional charging

Improving Battery Safety – more than regulations and standards: Design and control

Safety by design in the cell: (solid state is still not “intrinsically safe design”)

- Improving chemistry in anode/cathode/electrolyte
- Battery cell component design, morphology/metrology/chemistry at the molecular level
- Improved separator, current collector and package designs

Safety through improved cell manufacturing processes

- Improved processing and quality control from raw material through formation
- Traceability of materials
- Improved machine controls and AI-driven process monitoring/adjustment
- Damage-tolerant cell casings/components

Safety through improved system design

- Passive Propagation Resistance (failing cell has minimal effect on others)
- Improved thermal management (cooling/heating/uniformity)
 - Low conductivity & immersion coolants
- Improved charge balancing
- Improved monitoring, control, and detection
 - New sensors/control:
 - Cell venting detection
 - Impedance spectroscopy
 - Cell stress/strain/internal pressure
 - Pack coolant leakage/water intrusion



New China Standard Task Forces for 2026



Aluminum-Plastic Composite Film for Solid-State Batteries	Predictive Maintenance Solutions and Technical Guidelines for the Lithium Battery Industry	Technical Standard for Safety Monitoring and Early Warning of High-Voltage Transmission Towers Based on BeiDou
Technical Specifications for Immersed Liquid-Cooled Battery PACKs in Energy Storage Systems	Nickel-Coated Copper Foil for Solid-State Batteries	Base Film for Composite Collectors in Lithium-ion Batteries - Part 1: Polyester Film
Technical Guidelines for Immersed Cooling Systems for Lithium-ion Batteries in Energy Storage	Ultra-Thin Copper Foil with Carrier for IC Substrate Packaging	Base Film for Composite Collectors in Lithium-ion Batteries - Part 2: Polypropylene Film
Containerized Energy Storage Fire Protection System Design and Selection Guide	Extra-Thick Electrolytic Copper Foil for High-Power Printed Circuit Boards (PCBs)	Polyimide (PI) Separator for Lithium-ion Batteries
Protection and Testing Methods for Thermal Runaway in Energy Storage Lithium-ion Batteries	Rolled Copper Foil for FPC Boards in New Energy Vehicle Power Batteries	Weather-Resistant PVDF Film for Solar Panel Module Backsheet Packaging
Technical Requirements for Coolant Application and Selection in Immersion Liquid-Cooled Energy Storage Systems	Titanium-Based Coated Anodes for PCB Electroplating	Ultra-Thin Polypropylene Film for New Energy Vehicle Capacitors
Testing Methods for Immersion-Cooled Energy Storage Station Coolants	Titanium Anodes for Copper Etchant Recovery	PET Hot-Pressed Insulating Adhesive Film for CCS Busbar Integration
Fire Control Blankets for Lithium-ion Battery Incidents	Technical Requirements for NdFeB Magnetic Materials and Components for Humanoid Robots	Hot-Pressed Insulating Adhesive Film for Lithium-ion Battery Module Side Plates
Safety Welding Technical Standards for Lithium Battery Module PACKs		Sensors and Modules for Battery Energy Storage System Safety Monitoring
		Thermal Runaway Detection Sensors and Modules for Power Batteries
		NTC Thermistor for Integrated Busbar (CCS) Applications
		Technical Standards for Integrated Monitoring and Control Units of New Energy Vehicle Thermal Management Systems
		Flame-Retardant Foamed Liquid Silicone Rubber for New Energy Vehicle Battery Packs

Circled indicates
Safety-related Task
Forces

Standard preparation schedule:

- (1) Project research stage: October to December 2025
- (2) Drafting stage: January to February 2026
- (3) Soliciting opinions stage: March to April 2026
- (4) Standard approval stage: May 2026
- (5) Standard approval stage: June 2026

SAE Battery Standards Committees



850+ Committee Membership Individual Participants:

- Engineers, Scientists, Subject Matter Experts (SME's)

181 Represented Employers

- OEM's, Suppliers, Government, and Academia

32 Subcommittees

41+ Published Battery Documents

Committees develop 3 documents:

- Technical Information Reports
- Recommended Practices
- Standards



Working with Industry leaders!





Battery Committees: 2026

[BC1 Battery Safety Standards Committee](#)

[BC2 Battery Standards Testing Committee](#)

[BC3 Battery Standards Label & Tape Committee](#)

[BC4 Battery Transportation Committee](#)

[BC5 Battery Size Standardization Committee](#)

[BC6 Starter Battery Committee](#)

[BC7 Truck Battery Systems Committee](#)

[BC8 Battery Standards Fuel Economy & Range Committee](#)

[BC9 Battery Standards Advanced Battery Concepts Committee](#)

[BC10 Battery Standards Recycling Committee-](#)

[BC11 Battery Global Traceability Committee](#)

[BC12 Battery Test Equipment Committee](#)

[BC13 Battery Terminology Committee](#)

[BC14 Battery Materials Testing Committee](#)

[BC15 Secondary Battery Use Committee](#)

[BC16 Start-Stop Battery Committee](#)

[BC17 Battery Diagnostics](#)

[BC18 Battery Field Discharge and Disconnect Committee](#)

[BC19 Battery Systems Connection Committee](#)

[BC20 Battery Management Systems](#)

[BC 21 Battery Thermal Management Committee](#)

[BC22 Bus Battery System Committee](#)

[BC23 Battery Systems Adhesives-Sealants-Heat Transfer Materials](#)

[BC24 Battery Sensors Committee](#)

[BC25 Construction/Agricultural/Off Road Rechargeable ESS Committee](#)

[BC26 Micro mobility Battery Standards Committee](#)

[BC27 Truck Battery Systems](#)

[BC29 Battery Swapping Committee](#)

[BC30 Battery Pack Venting Committee](#)

[BC31 Insurance](#)

[BC32 Vehicle Platform Power Management Committee](#)

[First Responders Task Force](#)

Global Committee membership addressing critical industry needs from micromobility to HVOR, aerospace, and marine

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 - Impedance spectroscopy
 - Cell stress/strain/internal pressure
 - Pack coolant leakage/water intrusion



New Volunteer Information (Electrification Standard Development)

Please feel free to scan this QR code or click on the link below which takes you to the volunteer packet for all prospective members of our Electrification Committees



Thank you!

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<https://standardsworks.sae.org/standards-committees/battery-standards-discussion-forum#resources&publicResource=1eaa1960-50b4-40ad-b150-6b0393112ce9>