2025 Whitepaper

Factorial®

Quasi-Solid-State Battery Breakthroughs

Unlock Safer, Lighter, and more Powerful Solutions for eMobility.

www.factorialenergy.com

Contents

Introduction

The rapid adoption of electric vehicles (EVs) and the expansion of eMobility applications hinge critically on advancements in battery technology. Despite significant progress, safety and range remain paramount concerns for prospective EV buyers[1]. Additionally, the capabilities of drones, e-boats and electric vertical take-off and landing (eVTOL) aircraft are hampered by the absence of high-power batteries capable of meeting their demanding operational requirements[2].

Solid-state batteries (SSBs) have emerged as a promising solution to these challenges, offering the potential for more energy-dense, lighter, safer, and more powerful batteries. However, the marketplace is rife with claims about SSBs that often fail to materialize, leading to skepticism and uncertainty among stakeholders[3].

This white paper cuts through the noise by presenting real data on the current state of quasi-solid-state batteries (QSSBs) developed by Factorial. We will highlight the breakthrough performance metrics that meet the expectations of customers, automotive original equipment manufacturers (OEMs), and other stakeholders, demonstrating how these innovations can make the widespread adoption of EVs and eMobility applications a reality.

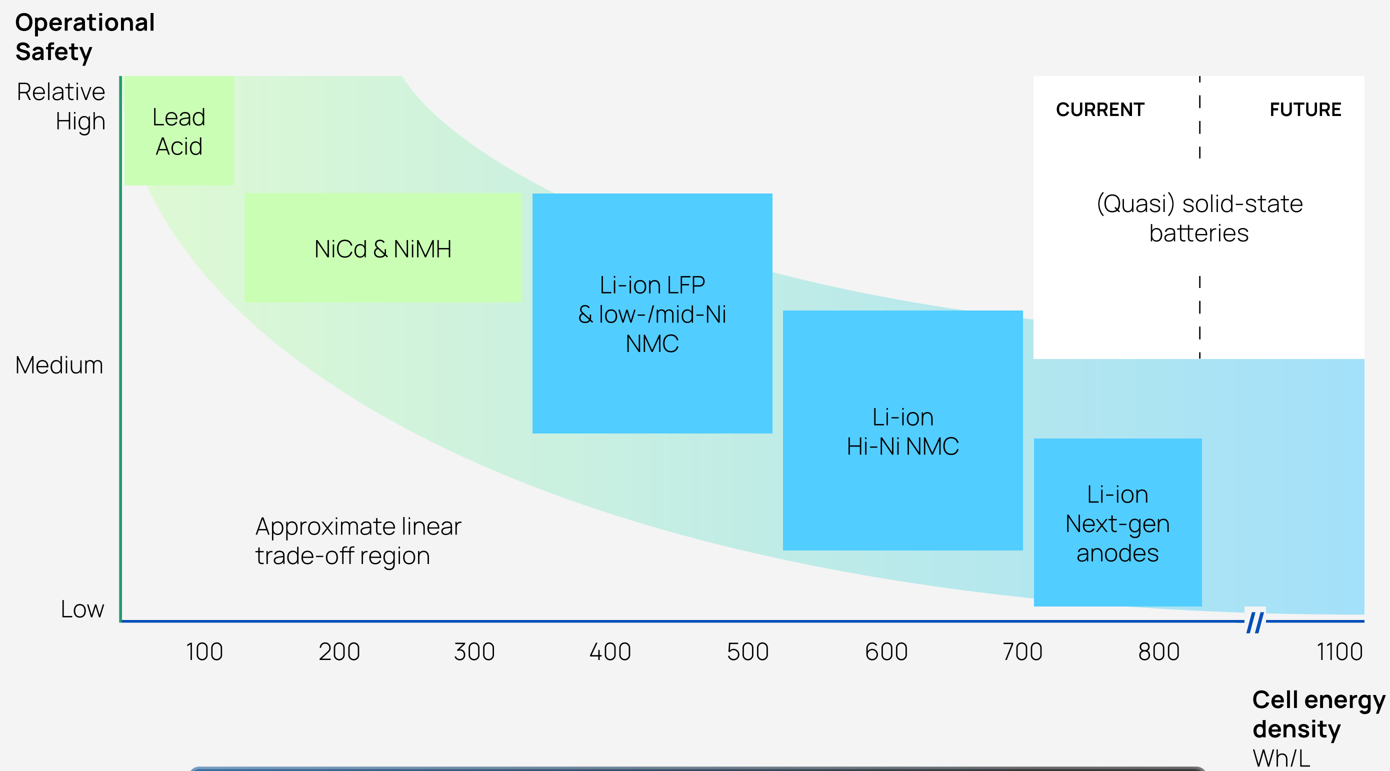
Limitations of Two Key Lithium-Ion Battery (LIB) Technologies

The current landscape of battery technology for EVs presents a significant challenge in balancing performance, cost and safety.

The LIB industry has been bifurcating into two predominant battery chemistries, Lithium Iron Phosphate (LFP) and High Nickel Cathode Materials (NCX). Each poses distinct advantages and limitations that impact their suitability for widespread EV adoption.

Over the last 10 years, LFP has transformed from an almost obsolete technology into a dominating product while NMC from the blockbuster into a slow growing territory.

(Q)SSBs bypass the common battery safety-energy density trade-off



Battery technology today has a trade-off between energy density and safety, leaving a gap in what the market needs.

Limited Range of LFP Batteries

LFP batteries were invented by Nobel Laureate Prof. John Goodenough[4] [5], in the early 1990s and have been recognized for their cost-effectiveness, safety and long cycle life. They offer a stable chemistry with a lower risk of thermal runaway. The absence of relatively expensive nickel and cobalt results also in rather low cost of LFP cells making them a reliable choice for EV and stationary storage applications.

However, LFP batteries suffer from **a critical limitation: their energy density is relatively low,** resulting in a limited driving range for EVs. Despite the lower cost, this constraint poses a significant barrier to consumer acceptance, particularly for those who require longer travel distances on a single charge.

Safety and Cost Concerns with High Nickel Cathode Materials (NCX)-Based Li-ion Batteries

In early 2000s NCX-based lithium-ion batteries emerged from research from multiple global leading institutions, including but not limited to Argonne National Lab,[6] [7] Dalhousie University and Osaka City University[8] [9] (NCX mentioned here includes both Nickel Cobalt Manganese (NCM) and Nickel Cobalt Aluminium (NCA) cathode materials). NCX batteries started to be industrialized for EV applications starting from early 2010s and became a “new darling” for EV, energy storage and consumer electronics due to a higher energy density compared to LFP batteries, translating to a longer driving range or operating duration. In the mid 2010s, all major market research institutes forecasted that by 2025 the EV batteries market would be comprised of 80% of NCX and 20% or even less of LFP.[10] [11] [12]

However, towards the end of the decade as NCX improved its nickel content and energy density, it introduced significant safety concerns due to the instability of the cathode material and the liquid electrolyte at high temperatures. NCX, especially with higher nickel content, are more prone to thermal runaway and propagation, a phenomenon where a single cell failure can lead to a chain reaction, causing overheating and potential fires spreading from the affected cell to the entire battery pack. This high thermal propagation risk necessitates complex and costly safety and thermal management systems, which can compromise the overall system level energy density and affordability of the battery. Nevertheless, the cost improvement from NCX was not as fast as LFP which is not subject to as much raw material volatility such as for Nickel and Cobalt.

The Trade-off Between Safety and Range

The NCX boom in the end of 2010s was a strong indicator the market demanded higher performance batteries. However, limited performance improvements and recurring safety incidents cooled down NCX demand, therefore causing the pendulum to swing in the opposite direction, now rather favoring LFP batteries over NCX going forward, according to the latest forecasts.[13 14 15]

This trade-off presents a significant compromise for the EV industry, as consumers and manufacturers must choose between safer, more affordable batteries with limited range and more powerful batteries that pose greater safety risks.[16]

Addressing this trade-off is crucial for the advancement of EV technology. Factorial's advanced solid-state batteries aim to overcome these limitations by offering a solution that breaks through the theoretical limit of lithium-ion batteries by using lithium-metal based chemistries, and opening a new horizon to balance between performance, cost and safety, thereby enabling the broader adoption of electric vehicles and supporting the widespread growth of eMobility and energy storage applications.

02

The Solution
Quasi-Solid-State Batteries

The Solution: Quasi-Solid-State Batteries (QSSB)

Factorial's advanced quasi-solid-state lithium-metal batteries, branded as FEST® (Factorial Electrolyte System Technology), represent a significant leap forward in battery technology.

FEST® combines a lithium-metal anode, quasi-solid electrolyte, and a high-capacity cathode. This proprietary cell design merges the performance and safety advantages of solid-state electrolytes with the manufacturability of conventional lithium-ion batteries.

FEST® aims to revolutionize eMobility by providing more energy-dense, lighter, safer, and more powerful batteries.

Factorial's quasi-solid-state FEST® cell is designed with a lithium-metal anode, and high-capacity cathode.

Benefits of Factorial's FEST® QSSB Cell

Higher Energy Density

With a demonstrated 391 Wh/kg in an automotive B-sample,[17] FEST® cells offer a substantial increase in energy density of up to 50% compared to traditional lithium-ion batteries. This higher energy density translates into smaller and lighter batteries and eventually longer driving ranges for electric vehicles (EVs), addressing one of the primary concerns of EV consumers.

Quicker to Market

One of the standout features of FEST® is its high compatibility with existing lithium-ion battery manufacturing processes. This compatibility allows for a faster transition to mass production, reducing time to market and cost by leveraging existing manufacturing infrastructure.

High Power

FEST® cells are designed to deliver high power output (>1300 W/kg during continuous 4C discharge at an energy density >310 Wh/kg and >3000 W/kg pulse power), making them suitable for a wide range of applications, including high-performance EVs, drones, e-boats and electric vertical take-off and landing (eVTOL) aircraft without compromising on energy density.

Safer

The quasi-solid electrolyte used in FEST® cells significantly enhances safety by reducing the risk of thermal runaway and improving thermal stability with no self-heating until >100°C. This makes FEST® batteries inherently safer than conventional lithium-ion batteries.

How does QSSB technology compare to incumbent Li-Ion battery technology? At a very similar capacity and footprint to Factorial's FEST® B-Sample cell, the LG Energy LGES E101A battery cell, based on NCM chemistry, is one of the leading products currently commercially available from the incumbent lithium-ion battery manufacturers. It offers a gravimetric energy density of 287 Wh/kg and a volumetric energy density of 637 Wh/L.[18]

While these metrics are impressive, **the E101A cell is 30% heavier than the FEST®** B-sample, which also has an about 20% greater volumetric energy density. At the same time, the quasi-solid-state design of FEST® provides a thermally more stable alternative to the typically carbonate-based conventional liquid electrolytes and allows the same high power output in addition to its compatibility with existing manufacturing processes, positioning it as a transformative solution for the future of eMobility as witnessed by the real-world testing data of automotive-sized quasi-solid

Compare and Contrast

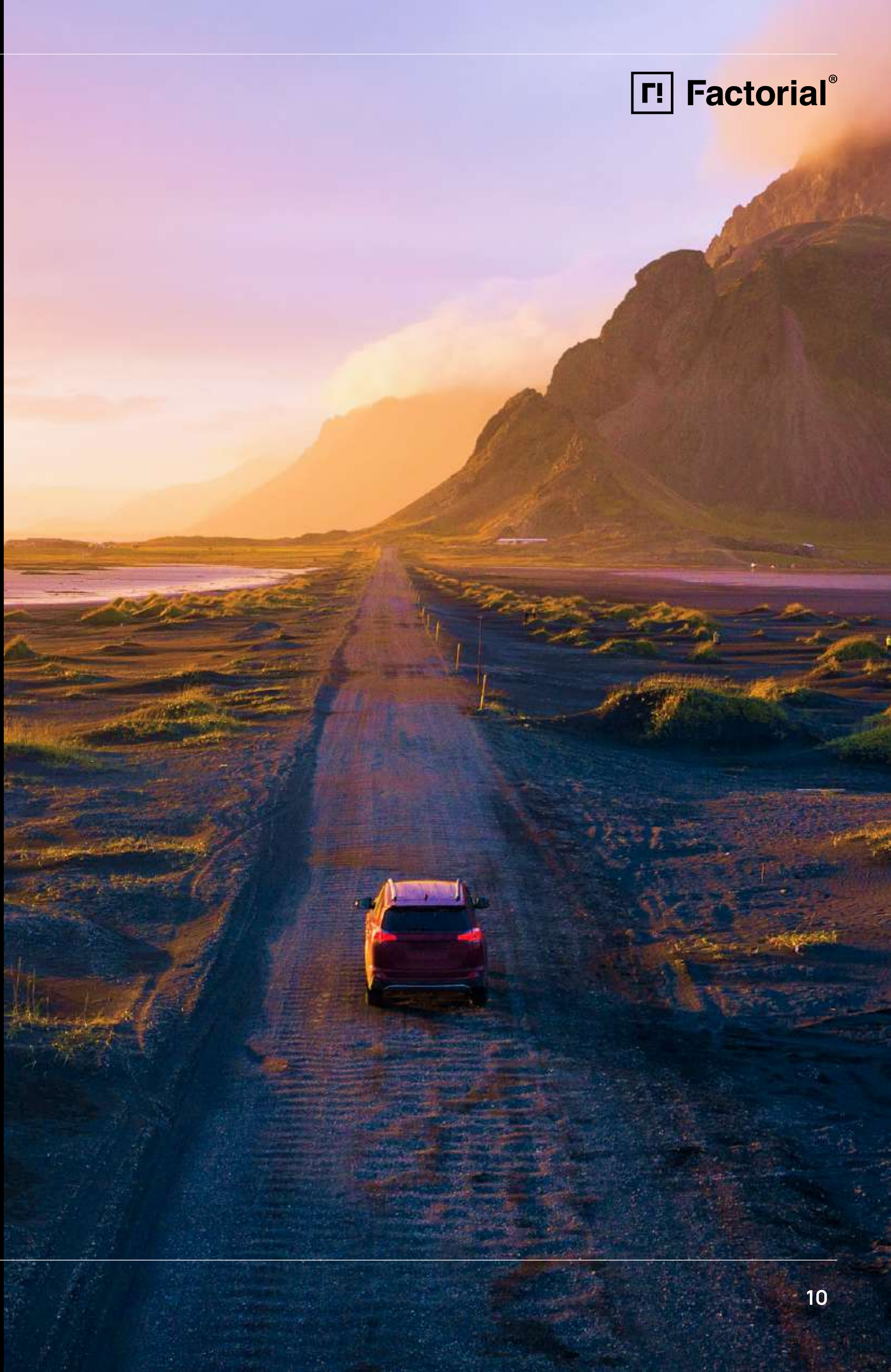
FEST® QSSB vs. Lithium-Ion Technology

Specification	Factorial® B-Design	E101A (Li-Ion) (Data from LG Energy Solution[1])	Gap (FE-LG)/LG x 100
Capacity (Ah)	106	101.8	4.1%
Nominal Voltage (V)	3.81	3.67	3.8%
Energy (Wh)	404	374	8.0%
Vol. Energy Density (Wh/L) (at 10% SOC)	835	637	31.1%
Vol. Energy Density (Wh/L) (at 100% SOC)	748 (8% Breathing)	N/A	17.4%
Specific Energy Density (Wh/kg)	391	287	36.2%
Dimension (mm)	463 × 110 × 10.35	580 × 112 × 9.00	-
Weight (kg)	1.02	1.303	(21.7%)

Factorial's quasi-solid-state B-sample FEST® cell is superior to best-in-class incumbent Li-ion battery technology

03

Data that Matters: Breakthrough Quasi-Solid-State Performance



Cycle Life

What is cycle life?

Battery cycle life typically refers to the number of full charge and discharge cycles a battery can undergo before its capacity falls below a specified threshold, usually 80% of its original capacity. This metric is crucial for assessing the longevity and durability of a battery, especially in applications like EVs where frequent charging and discharging are routine.

Why it matters?

Cycle life is an important KPI for automotive partners. To be commercially relevant, a new technology needs to demonstrate at least 500 cycles, and even more is required during qualification, e.g. for automotive mass market application it requires at least 600 cycles for long range performance vehicles and up to 1000 cycles for shorter range value market vehicles, where a long cycle life is needed to off-set battery costs, which can make a large portion of vehicle cost.

The challenge

While (solid-state) R&D cells in small format below 10 Ah may seemingly be able to achieve these targets, the reality looks very different for large format prototype cells. With the larger format, manufacturing and engineering challenges come into play beyond the pure material properties, which can be handled at lab-scale for all kinds of solid electrolytes. Historically, scaling these technologies has been difficult for SSB developers for a variety of reasons including: material availability (affecting cost), brittleness of the larger format components of the cell during manufacturing and handling, and susceptibility to defects in the electrolyte and lithium-metal anode. Finally, the larger prototypes behave very differently from small scale cells, and uneven lithium deposition, pressure gradients and higher heat generation can quickly accelerate cell, and inhomogeneous lithium deposition, pressure gradients and higher heat generation can quickly accelerates cell degradation. As a consequence, challenges like electrolyte and other material stability can no longer be masked.

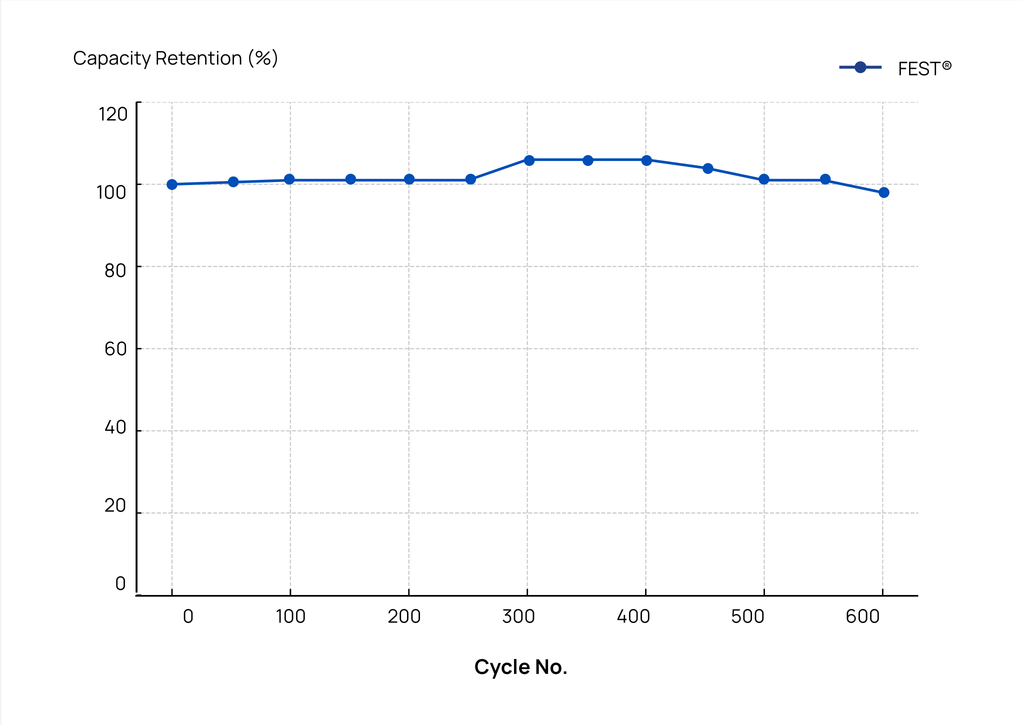
The solution – Factorial Electrolyte System Technology - FEST®

Factorial's development has focused on the entire electrolyte and cell system paying attention to all these aspects and resulting in a QSSB cell with high manufacturability and scalability, while maintaining class-leading cycle life performance at a 77 Ah cell level, which meets automotive standards. Factorial has developed proprietary process technology to handle lithium metal anodes during cell assembly to homogeneously distribute the polymer-based quasi-solid electrolyte across a cell that is roughly 50 cm long, 10 cm wide and 10 mm thick.

Such cells tested under rigorous automotive conditions have achieved more than **600 full charge-discharge (SOC 5% - 95%) cycles** under both a constant current (0.2C charge and 1C discharge) as well as a dynamic worldwide harmonized light vehicles test procedure (WLTP) load profile, where cells are charged at 0.2C and discharged simulating a series of varying power drive and recuperation cycles.

Cycle Life

77 Ah Lithium Metal Cells Demonstrate Strong Performance Across Drive Cycles



TEST CONDITIONS

0.2C Charge.

WLTP discharge cycle in usable SOC range 5-95% at 30°C.

KEY FINDINGS

600+ Cycles

This equates to:

600,000 km range
over a lifetime

60 ton CO_2
emissions avoided

ASSUMPTIONS

120 kWh pack with 1,000 km electric driving range, zero-emission electricity grid.

Average CO2 emissions of 106g per km for new passenger cars in 2023.[19]

Safety

Key battery cell safety parameters: Electrochemical, thermal and mechanical stability

Electrochemical stability

refers to the battery's ability to maintain stable interfaces with both anode and cathode during charge and discharge cycles. Electrochemical stability is crucial to prevent unwanted side reactions that can lead to capacity loss or overheating, as well as to prevent the formation of so-called lithium dendrites, which are microneedles of lithium growing from the anode through the separator to the cathode and can cause a short circuit leading to strong heat evolution or even fires.

The **thermal stability** of a battery cell is its most critical parameter and indicates the battery's ability to withstand and manage heat generated during operation, e.g. during fast charging. High thermal stability ensures that the battery does not overheat, which can cause thermal runaway—a dangerous chain reaction where the battery temperature uncontrollably rises, potentially leading to fires or explosions.

Especially for the automotive industry, **mechanical stability** is also of great importance as it involves the battery's structural integrity under physical stress, such as vibrations, pressure changes, or impact during the event of an accident. Mechanical stability is essential to prevent internal short circuits and maintain the battery's performance and safety over its lifespan.

Safety is Multifaceted

Each Stability Aspect Brings Unique Advantages

Quasi-Solid State Battery Advantages	Vehicle Level Advantages
(Electro)chemical Stability	Improved cycle life, calendar life, improved over(dis)charge
Thermal Stability	Reduced need for thermal protection: Mica/heatshields Simplified cooling systems: Reduces need for **active cooling** Higher tolerance for high-temperature exposure, enabling **fast charging** and **high-power applications**
Mechanical Stability	Improved safety handling Allow for **crash zone optimization**

EUCAR RATING[20]

The European Council for Automotive R&D (EUCAR) has established a hazard severity level (HSL) classification system to assess the safety of automotive batteries.

The EUCAR rating ranges from HSL0 (no effect) to HSL7 (explosion), providing a standardized way to evaluate the outcomes of safety tests, such as overcharge, thermal abuse, and mechanical impact. This rating system helps manufacturers and regulators ensure that batteries meet the necessary safety standards for automotive applications.

Factorial's quasi-solid 106Ah lithium-metal FEST® cells achieve HSL 3 or lower in third party automotive testing. Detailed results are in the next page.

Hazard Level	Description	Classification Criteria & Effect
0	No effect	No effect. No loss of functionality.
1	Passive protection activated	No effect; no leakage; no venting, fire, or flame; no rupture; no explosion; no exothermic reaction or thermal runaway. Cell reversibly damaged. Repair of protection device needed.
2	Defect/Damage	No leakage; no venting, fire, or flame; no rupture; no explosion; no exothermic reaction or thermal runaway. Cell irreversibly damaged. Repair needed.
3	Leakage Δ mass < 50%	No venting, fire, or flame; no rupture; no explosion. Weight loss <50% of electrolyte weight (electrolyte = solvent + salt).
4	Venting Δ mass ≥ 50%	No fire or flame; no rupture; no explosion. Weight loss ≥50% of electrolyte weight (electrolyte = solvent + salt).
5	Fire or Flame	No rupture; no explosion (i.e., no flying parts).
6	Rupture	No explosion, but flying parts of the active mass.
7	Explosion	Explosion (i.e., disintegration of the cell).

a) External short circuit (HSL 2)

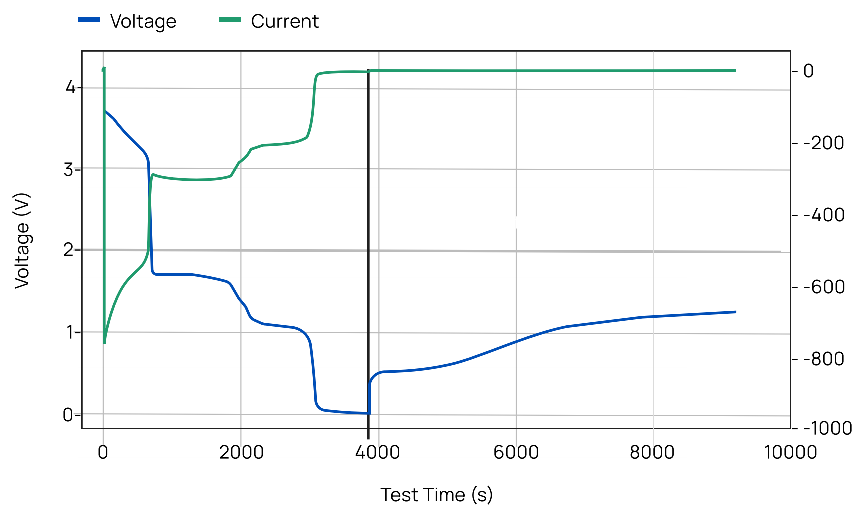
The external short circuit test is a crucial safety evaluation used to determine how a battery responds to a direct short circuit across its terminals. In this test, the positive and negative terminals of the battery are connected with a low-resistance conductor, creating a high current flow. This simulates conditions that might occur if the battery's terminals were accidentally bridged by a conductive object or during (un)intentional misuse.

In this specific test carried out through an independent third party, a 106 Ah FEST® cell charged to 100% SOC was short circuited by an external resistor of ‹ 5 mΩ for 60 minutes at an ambient temperature of 60°C. Upon the initially high current draw from the shorted cell no dramatic temperature increase beyond the self-heating threshold was observed until the cell was completely discharged to 0 V after ~50 minutes. Factorial's FEST® cell did not show any sign of weight loss, venting, smoke or thermal runaway resulting in the pass of the test with HSL 2.

External Short Circuit

106 Ah Lithium Metal FEST® Cells

PASSED HSL 2



PRE-TEST

POST-TEST

TEST CONDITIONS

100% SOC

Short of ‹ 5mΩ applied in ‹ 1s

Short circuit is maintained for a duration of 60 minutes.

Perform test at room temperature.

RESULTS

No sign of leaking, venting, smoke, or thermal runaway.

No weight loss during test.

Max current 760 A.

b) Overcharge to 10 V (HSL 3)

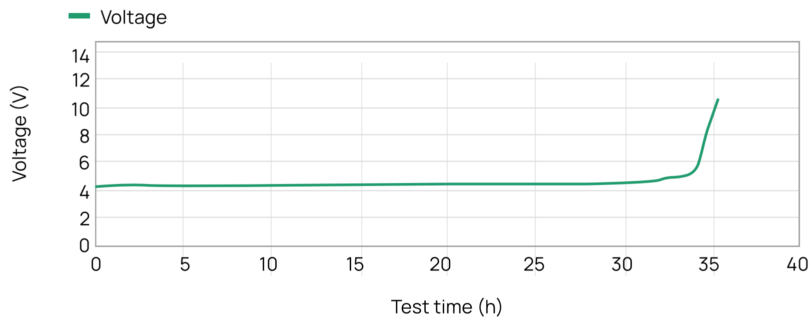
An overcharge test assesses how a battery responds when charged beyond its maximum voltage limit. In this test, the battery is subjected to a charging voltage higher than its rated capacity, simulating conditions that might occur due to a malfunctioning charger or charging system, e.g. upon failure of other cells connected in series.

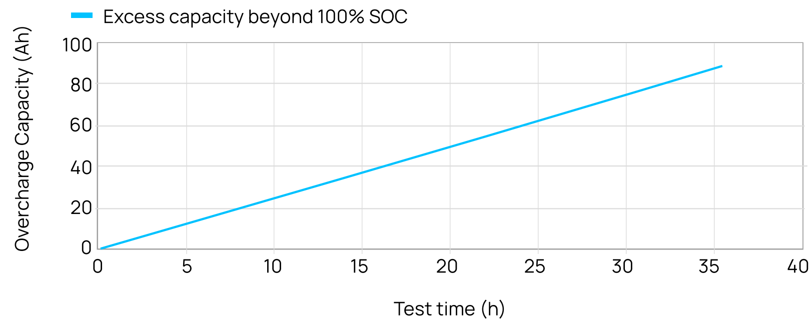
In this specific test carried out through an independent third party, a 106 Ah FEST® cell already fully charged to 100% SOC was forced to continuously overcharge at a constant current of 2.5 A at 60 °C until the cell voltage reached 10 V corresponding to an overcharge to roughly 180% SOC. After exceeding ~4.5 V electrolyte decomposition seemingly set in (long flat plateau in the voltage curve) and no further self-heating is observed. As the cell shows minor mass loss and opening of the pouch on the cathode tab, Factorial's FEST® technology passes this test with HSL 3.

Overcharge

106 Ah Lithium Metal FEST® cell

PASSED HSL 3





PRE-TEST

POST-TEST

TEST CONDITIONS

100% SOC

2.5 A charge to 4.45 V, continue at 2.5 A until HSL 4 or 250% SOC (267 Ah) or 10 V

Perform test at 60 °C

RESULTS

Hit voltage limit of 10 V.

No thermal runaway.

c) Mechanical crush (HSL 2)

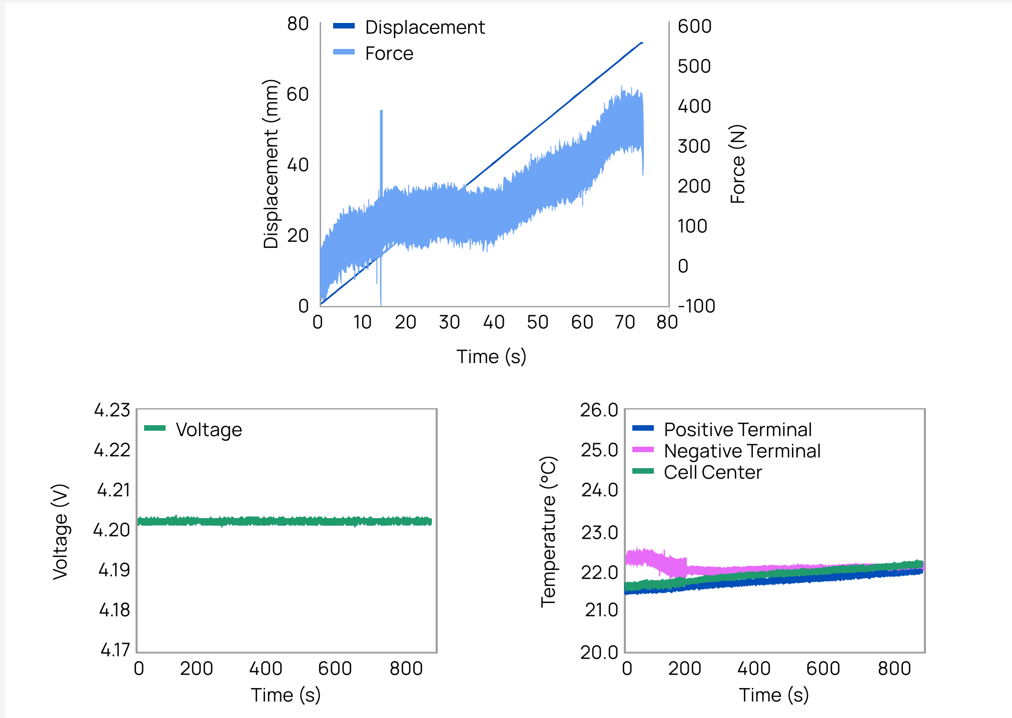
The mechanical crush test aims to determine how a cell reacts to extreme mechanical deformation and stress. The battery cell is subjected to a compressive force applied between a static flat surface and an indenting pillar, simulating conditions such as a vehicle crash or impact from road debris, where the surrounding battery pack is severely intruded from the external and leading to deformation of individual cells.

For pouch cells, three main axis are tested for mechanical crush: the z-axis perpendicular to the flat surface of the cell, and both, short and long sides of the pouch in x- and y-direction. In this specific test carried out through an independent third party, all crush tests were performed at room temperature on 106 Ah cells charged to 100% SOC and until a 15% deformation was achieved in the respective direction.

Mechanical Crush : X- Axis

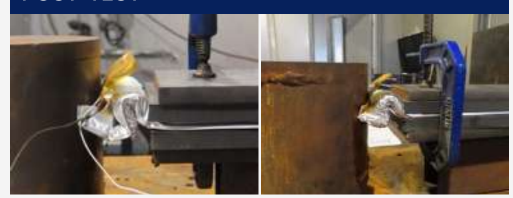
106 Ah Lithium Metal FEST® cells

PASSED HSL 2



PRE-TEST

POST-TEST



TEST CONDITIONS

100% SOC

2 mm/s till cell voltage 0 V, or 15% deformation, or 100 kN force

RESULTS

No thermal runaway.

No electrolyte leak.

Max displacement 73.58 mm.

Max force 440 N.

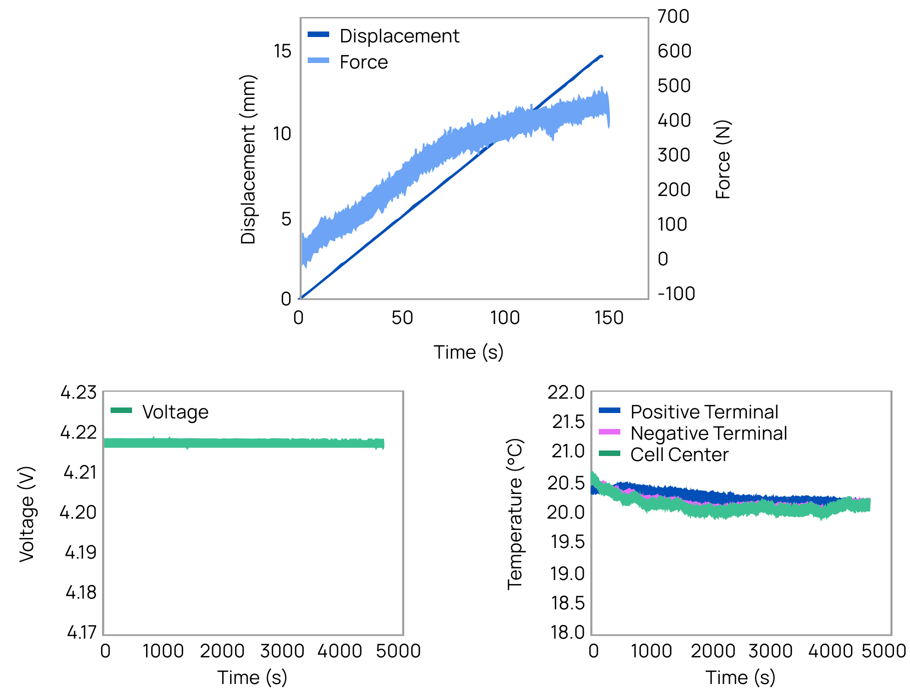
Max temperature 22.55 °C.

In all cases no significant temperature rise nor voltage drop was observed, despite the extreme deformation along the x-axis (long side of the pouch), where tab and cell are rolling up/folding in a 180° angle. Remarkably, Factorial's FEST® cells did not show any sign of weight loss, venting, smoke or thermal runaway resulting in the pass of the test with HSL 2.

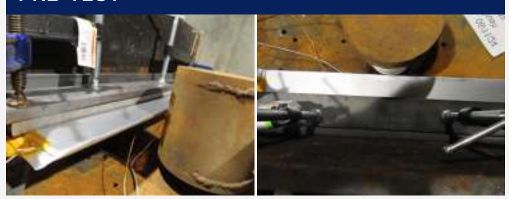
Mechanical Crush: Y - Axis

106 Ah Lithium Metal FEST® cell

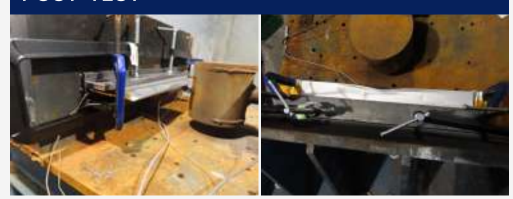
PASSED HSL 2



PRE-TEST



POST-TEST



TEST CONDITIONS

100% SOC

2 mm/s till cell voltage 0 V, or 15% deformation, or 100 kN force

RESULTS

No thermal runaway.

No electrolyte leak.

Max displacement 14.74 mm.

Max force 489.7 N.

Max temperature 20.69 °C.

d) Thermal hot box test (HSL 3)

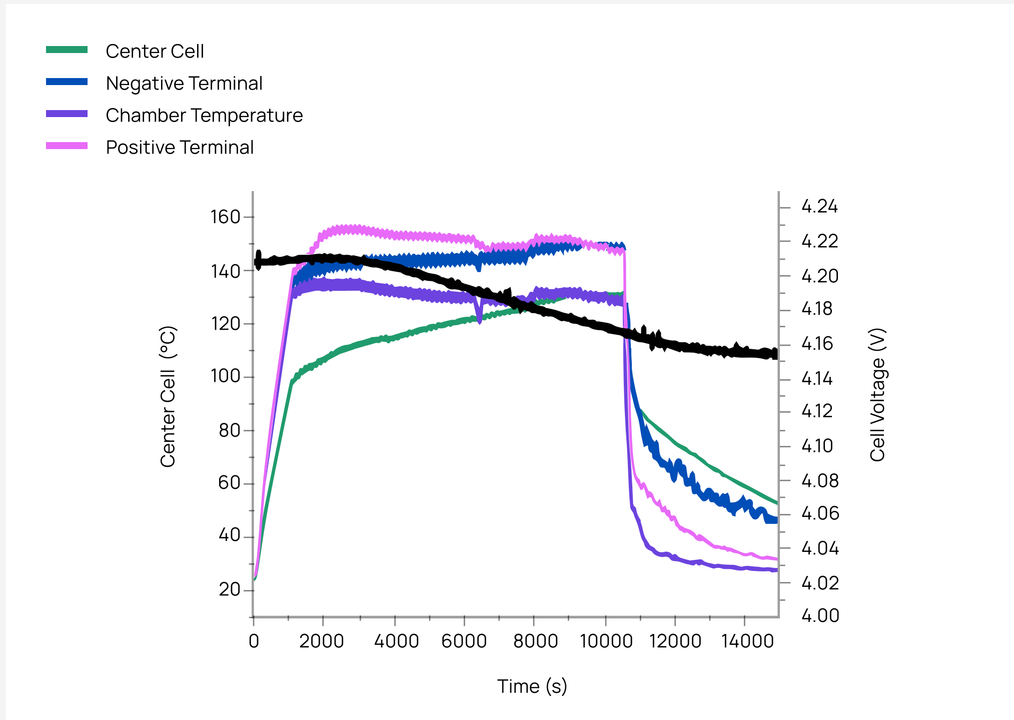
The cell's ability to withstand high temperatures is evaluated via a thermal abuse or hot box test. A battery is placed in a temperature-controlled chamber and exposed to elevated temperatures to simulate extreme conditions during operation (e.g., high current flow at an already high environmental temperature) or in the event of a thermal incident of a neighboring cell (i.e. resistance to thermal propagation).

In this test by an independent third party, a 77 Ah cell at 100% SOC was heated from room temperature to 130 °C. Once the cell's center measured 130 °C (~150 min), it was held there for 30 min. After that a ~40 mV voltage drop was observed, and as the chamber cooled, the cell showed a steady relaxation to below 60 °C. As the result of a minor mass loss and opening of the pouch on the cathode tab, Factorial's FEST® technology passes this test with HSL 3.

Thermal Hot Box

77 Ah Lithium Metal FEST® cell

PASSED HSL 3



PRE-TEST

POST-TEST

TEST CONDITIONS

- 100% SOC
- RT to 130 °C, 5 °C/min
- Hold cell at 130 °C for 30 min

RESULTS

- Weight loss 5.3%.
- Cell does not self-heat after exposure.
- Voltage stays almost constant.

e) Forced internal short circuit (nail penetration, HSL 2)

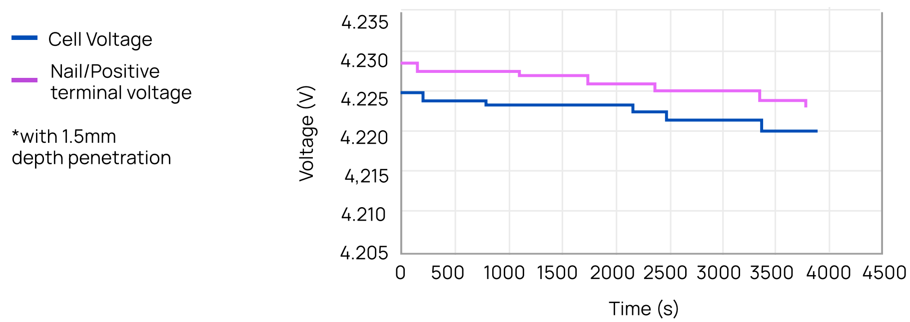
This test evaluates battery safety under a mechanically induced short circuit, where electrode layers are forced into contact by a sharp nail, simulating the impact of severe manufacturing defects (e.g., metal particles or dented collectors) and external penetration (e.g., during storage and handling of the cells or malfunction of the pack assembly robots).

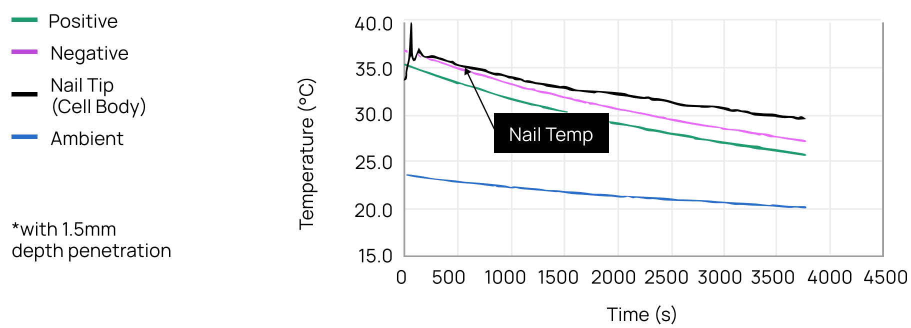
In this test carried out through an independent third party, a 106 Ah cell charged to 100% SOC and heated to 40 °C, was punctured >1.5 mm deep with a 1.0 mm thick nail, penetrating 9 cathode layers. Over one hour, the cell voltage dropped by 5 mV; the nail temperature rose ~2 °C, then declined to near room temperature. No venting, smoke, or self-heating occurred. The cell's mild response to the internal short leads to a pass at HSL 2 for Factorial's FEST® technology.

Forced Internal Short Circuit

106 Ah Lithium Metal FEST® Cell

PASSED HSL 2





PRE-TEST

POST-TEST

TEST CONDITIONS

Cell charged to 4.25 V, 100% SOC

0.01 mm/s, 1 mm steel, or SUS nail, nail tip 30°

STOP CRITERIA

Nail / positive terminal voltage drop until 50 mV or more

Thermal runaway happens

Penetration depth with 1.5 mm

RESULTS

Reached full penetration depth of 1.5 mm.

Voltage drop of 8 mV for DUT 1 and 5 mV for DUT 2.

No thermal runaway.

Penetrated 9 layers of cathode.

Fast Charging

What is fast charging?

Fast charging refers to the ability to charge an EV battery at a significantly higher rate than standard charging methods. This process reduces the time required to restore the battery's energy, making EVs more convenient for users. The first generation of fast charging (i.e. 50-250 kW chargers, which still are the most widespread technology)[21] can take anywhere from 30 minutes to an hour to charge a battery to 80% capacity, depending on the battery size and the charging infrastructure. For instance, Tesla's Model 3 Performance can be charged at a maximum power of 210 kW from 10 to 80 percent in 30 minutes.[22] Current fast-charging technologies, such as DC ultra-fast chargers, can deliver power levels of up to 350 kW, allowing for rapid energy transfer in less than 30 minutes, but also have higher requirements on the battery to support this charging rate.

Why fast charging is so important for EV adoption?

One of the primary barriers to the widespread adoption of EVs is range anxiety—the fear that a vehicle will run out of power before reaching its destination.

Fast charging addresses this concern by significantly reducing the downtime required for recharging, thus making EVs more practical for long-distance travel and daily use.

According to the McKinsey Mobility Consumer Survey, fast charging being the top concern for potential EV owners can help alleviate range anxiety and encourage more consumers to switch to electric vehicles.[23]

The challenge of fast charging for solid-state

Charging a premium EV with an assumed battery energy capacity of 150 kWh at a power of 350 kW from 10 to 80% would mean charging the battery in 20 minutes, or in other words, at 3C or more. Achieving such high current rates is very challenging for large format solid-state batteries. Minor material inconsistencies and defects in the solid electrolyte layer can limit its conductivity compared to liquid electrolytes. This means ions move more slowly through the solid material, which can limit the rate at which the battery can be charged. In addition, the interfaces between the solid electrolyte and the electrodes can be unstable, leading to increased resistance and excessive heat evolution which may cause material degradation, losses in capacity and charging efficiency during fast charging. In the worst case, this instability can cause the formation of lithium dendrites that can short-circuit the battery.

The solution: Factorial Electrolyte System Technology – FEST ®

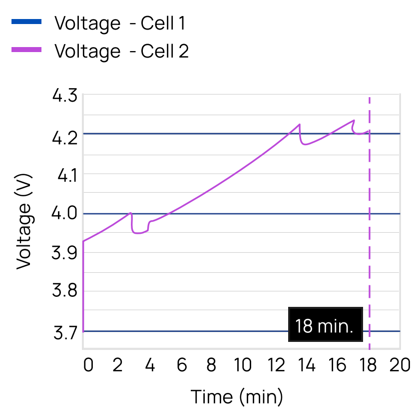
Electrolyte scientists at Factorial are constantly exploring new materials and designs to enhance ionic conductivity, stabilize interfaces, and manage thermal and mechanical stresses in lithium-metal batteries more effectively.

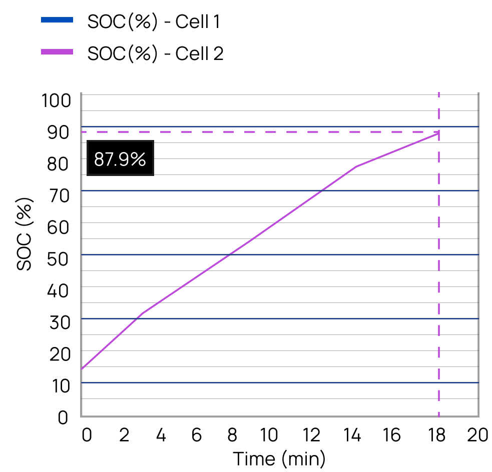
The solution is a polymer-based quasi solid-state electrolyte which is not only highly compatible with existing Li-ion battery manufacturing equipment, but also stable towards high capacity NMC cathodes and the lithium-metal anode.

As a consequence, Factorial's FEST® cells have demonstrated repeatable fast charging from 15% SOC to >90% SOC in 18 minutes during qualification of 77 Ah cells under automotive standards. Importantly, for a more energy dense cell, this means more energy per minute compared to a conventional cell.

Fast Charging (77 Ah)

77 Ah Lithium Metal FEST® Cell





Factorial's AI Charging Breakthrough

Fast charging is a high stress condition that degrades batteries over time.

Using Factorial Energy's proprietary digital platform Gammatron™ we have developed AI-optimized fast-charge algorithms that utilize non-linear multi step profiles to optimize stress and temperature conditions during charging. The resulting protocols could improve the cycle life using consecutive fast charging by an incredible 100%.

TEST CONDITIONS

Charge C/3 to SOC15% at 25 °C.

Fast charge protocol to SOC90% at 30 °C RT to 130 °C, 5 °C/min.

KEY FINDINGS

18 Minutes

Charging time

15% - 90% SOC

GET IN TOUCH

If you want to learn more and how this could be directly applied to optimize your operating profile reach out to us on our contact page at

https://factorialenergy.com/contact-us/

Temperature Range

Current operating temperature of Li-ion and solid-state batteries

Lithium-ion batteries typically operate optimally within a temperature range of 15 °C to 35 °C. Outside this range, their performance can degrade significantly. For storage, the recommended temperature range is -20 °C to 25 °C. However, leading incumbent battery suppliers specify their cells for a temperature range from -30 °C to 55 °C (operation) or even 60 °C (storage).[24] In contrast, many solid-state batteries, which use solid electrolytes instead of liquid ones, have a lower conductivity and frequently operate best at slightly elevated temperature of ~45 °C. This is especially the case for sulfide and oxide/ceramic-based solid-state batteries, but also observed for some polymer-based systems under development.

Extreme weather can degrade range and pose safety risks[25]

Extreme weather conditions can severely impact the performance and safety of batteries. In cold temperatures, the electrolyte in lithium-ion batteries can become more viscous, slowing down the movement of ions and reducing the battery's capacity and efficiency. Similarly, solid-state batteries are even stronger impacted by the lower conductivity and negative temperatures. If the sluggish kinetics lead to uneven distribution of lithium ions near the anode interface, the locally concentrated plating of lithium can lead to the formation of dendrites, which is a severe safety risk for charging Li-ion batteries at low temperature. In hot conditions, the increased temperature can accelerate chemical reactions within the battery, leading to faster degradation. Especially the low stability of liquid electrolytes in combination with their extremely high flammability poses potential safety hazards such as the risk of thermal runaway. Overall, these effects can reduce the driving range of electric vehicles through more complex battery pack designs or in return pose significant safety risks during operation.

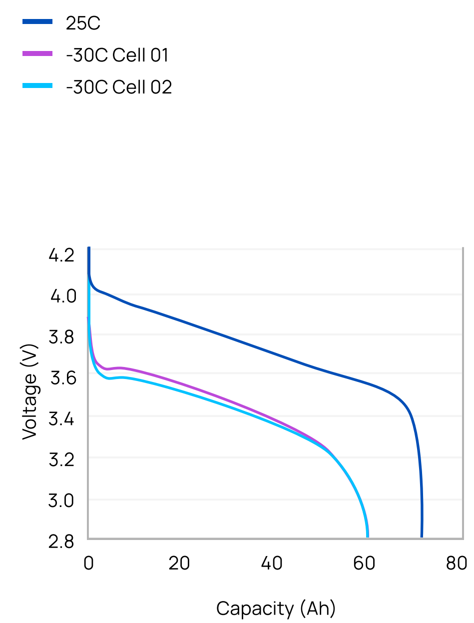
The solution: Factorial Electrolyte System Technology – FEST®

Factorial, addresses these challenges effectively utilizing a quasi-solid, polymer-based gel electrolyte that combines the benefits of both solid and liquid electrolytes. This innovative approach offers several advantages and allows a wide range of operating temperatures. Automotive-sized FEST® cells were demonstrated to operate efficiently across a broad temperature range from -30 °C up to 45 °C cell temperature.

The quasi-solid electrolyte is more stable and less prone to leakage or combustion, reducing the risk of thermal runaway and other safety hazards, not showing any self-heating to temperatures above 130 °C as evidenced by the hot box test. At the same time, the quasi-solid electrolyte enables faster ion transport, which supports higher charging rates and better efficiency. Even under extremely challenging temperature conditions such as -30 °C, the cell can be discharged to deliver 80% capacity compared to its room temperature capacity.

Low Temperature Performance

77 Ah Lithium Metal FEST® Cell



TEST CONDITIONS

Discharge capacity check at -30 °C

82.7% capacity retention comparing to discharge capacity at 25 °C

KEY FINDINGS

-30 C to 45 C

Operating temperature

Power Performance

What is high-power battery performance

High power performance in batteries refers to the ability to deliver a large amount of electrical power in a short period. Usually this is determined by the maximum current that can be drawn from a battery cell at a given voltage or in other words, how fast it can be discharged continuously or for short-time pulses of seconds to minutes. This capability is crucial for applications that require rapid acceleration, high torque, or quick bursts of energy. High power performance is typically measured in terms of power density (W/kg), which indicates how much power a battery can deliver per unit of weight.

Why high power is essential for several high-end applications

Premium EVs and especially sportscars require rapid acceleration and high torque to deliver the performance expected by enthusiasts. High power batteries enable sportscars to achieve impressive acceleration and maintain high speeds.

Similarly, also racing boats and luxury small-sized electric yachts benefit from the high power available from batteries to rapidly accelerate against the drag of seawater. When it comes to combining high power with high energy density aviation (eVTOL, eCTOL) and drone applications have the most demanding requirements to generate enough torque when quick bursts of energy are needed for takeoff, maneuvering, and sustained flight for which the high energy density of a lightweight battery is crucial as well. Finally, also power tools often require a high-power output to perform heavy-duty tasks like drilling or powering a chain saw efficiently and operate them at peak performance over extended periods.

The challenge of uniting high energy density with high power output

Usually, cells that have high power capability have a lower energy density. High power density often involves using materials and designs that allow for rapid ion movement, which is larger amounts of liquid electrolyte, higher electrode porosity and thinner electrodes. All these compromise energy density, whereas the design typically involves denser materials that may not facilitate fast ion movement. Also the structural design of other battery components, such as the thickness of current collectors and separators, reflects this trade-off between minimizing resistance for high power and maximizing capacity for high energy. Not least also the material selection for the electrodes (anode and cathode material) plays a crucial role.

High power cells often use smaller particles of active material to reduce resistance and enhance ion diffusion, while high energy cells use larger particles to store more energy.

The solution: Factorial Electrolyte System Technology – FEST®

At Factorial we solve these challenges with innovative approaches in materials science, engineering, and manufacturing to create batteries that can meet the demands of modern applications like high-performance EVs and electric drones. The ultra-thin lithium metal anode that we use in our FEST® Li-metal cells is already (energy) denser than any silicon or graphite anode in a lithium-ion cell could be and scientific literature has shown that high-power discharge is actually beneficial for the cycle life of Li-metal cells.[26] The ionic conductivity of the quasi-solid state electrolyte is already high and has been even further improved through AI-assisted optimization of its formulation using Gammatron™.

As a result, automotive-sized 77 Ah cells have achieved an outstanding 4C continuous discharge from 100% to 0% SOC delivering >90% of its rated capacity. This corresponds to a specific power output of >1300 W/kg continuously at an energy density >310 Wh/kg (at 4C discharge).

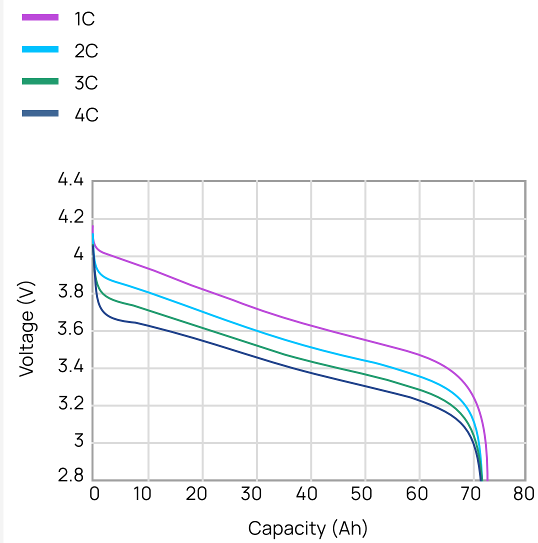
FACTORIAL'S AI MATERIAL DISCOVERY BREAKTHROUGH

AI-Assisted Electrolyte Optimization for High Power

AI-assisted optimization of the electrolyte's composition using our Gammatron™ digital platform evaluating thousands of possible electrolyte candidates for higher power capability with the same good thermal and electrochemical stability. Finally, Gammatron™ is also used to optimize cell design and electrode microstructure through advanced multi-scale modelling to ensure good electrical current and thermal paths within the cell.

High Power Performance

77 Ah Lithium Metal FEST® Cell



TEST CONDITIONS

C/3 Charge to 100% SOC (4.25V)

Discharge at 1C-4C full DOD at 25 °C

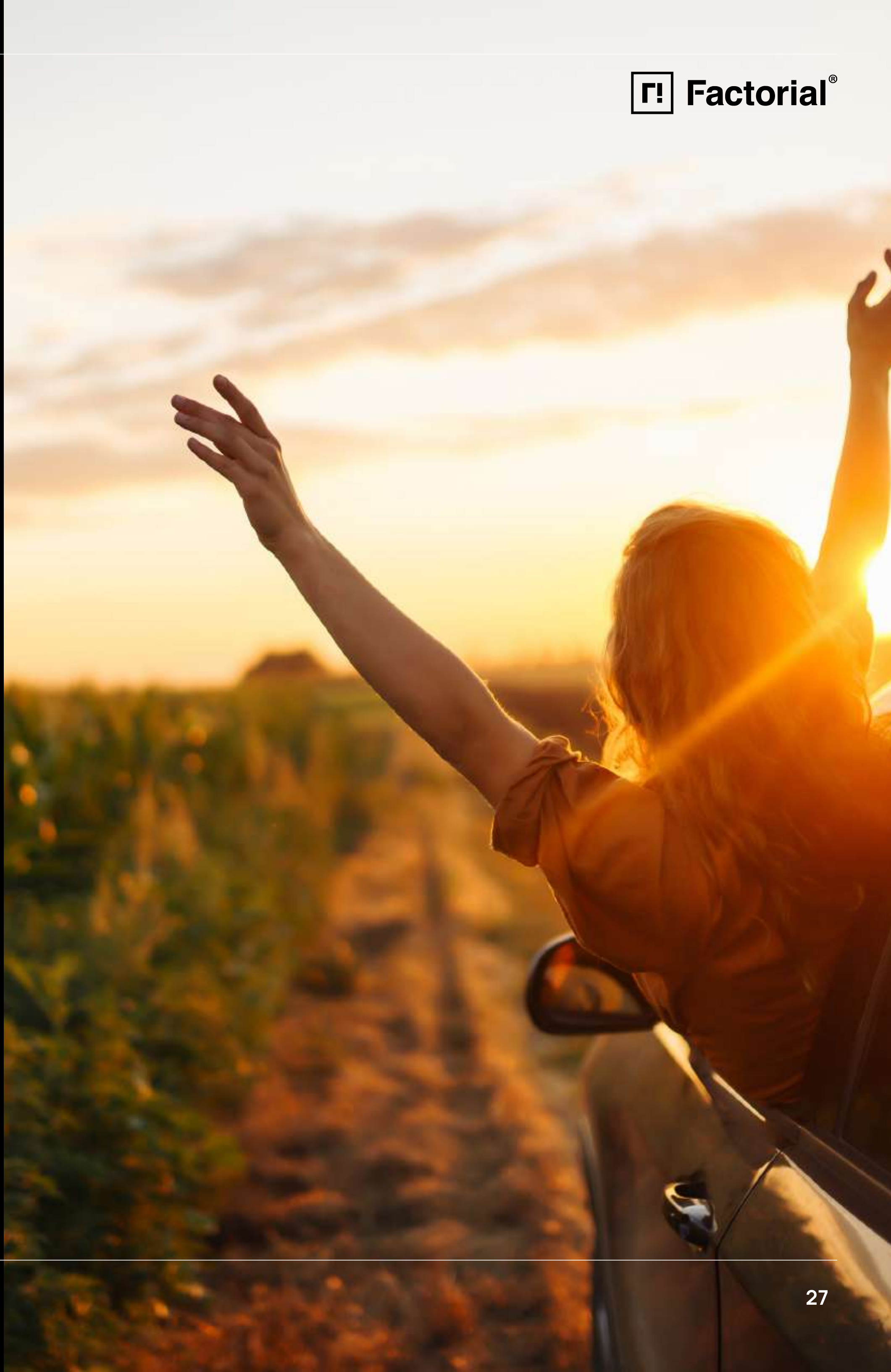
KEY FINDINGS

Obtained capacity listed in table below:

C-rate	Capacity (Ah)	Capacity Retention (%)
1C	71.6	94.5
2C	72.8	93.4
3C	71.9	93.1
4C	71.7	93.0

04

Solid-State is Integral to the Future of EVs and eMobility



Solid-State is Integral to the Future of EVs and eMobility

Factorial's quasi-solid-state battery technology represents a significant leap forward in the automotive industry, offering significantly greater energy density and thus, reducing vehicle cost at scale compared to the existing incumbent Li-ion battery technology.

With respect to other solid-state approaches, Factorial's QSSB offers enhanced cycle life, superior safety, rapid charging capabilities, a wide operational temperature range, and impressive power output, which makes the technology highly appealing for multiple applications beyond performance EVs in the aviation, marine and power tool domain.

These advancements position Factorial at the forefront of battery innovation, promising a more sustainable and efficient future for electric vehicles.

Where we still need to go

Despite these remarkable achievements on commercially relevant cells, there are areas that require ongoing development to fully realize the potential of quasi-solid-state batteries:

Continuous improvements on fast charging and operating temperatures

While current performance is impressive, further enhancements in fast charging times and the ability to operate efficiently across an even broader temperature range will be crucial to maximize vehicle level benefits for OEMs and consumers. To ensure this, Factorial is continuously improving its electrolyte formulation, cell design and fast-charge profiles in highly accelerated R&D cycles enabled through the proprietary AI platform Gammatron™. These improvements will ensure that the technology meets the diverse needs of consumers and various automotive applications in extreme weather and highly demanding charging scenarios.

Need for better domestic sourcing options and secure supply chain

As for the wider lithium battery industry, further strengthening the domestic supply chain and more possibilities for sourcing materials locally will be essential to reduce dependency on international suppliers. While Factorial is already forming multiple strategic alliances with local partners in its upstream supply chain, there is still great potential especially when it comes to the critical raw materials and their refinement into active battery materials. This will not only enhance the security of supply but also contribute to the overall sustainability of the technology.

Cost improvements

As the demand for quasi-solid-state batteries increases, economies of scale are expected to drive down costs going from prototype (MWh-scale) to automotive mass production (GWh-scale). With the high similarity of the FEST® cell production process compared to conventional Li-ion batteries, and being able to directly utilize about 80% of an existing manufacturing line, Factorial is confident that cost will be competitive at scale.

Conclusion

In conclusion, Factorial's quasi-solid-state battery technology is poised to revolutionize the automotive industry.

The benefits of Factorial's FEST® technology represent a significant advancement in battery technology, offering a higher energy density and robust solution to the challenges posed by the safety, performance, and longevity needs of electric vehicle batteries.

As we continue to address the challenges of fast charging, operating temperatures, supply chain resilience, and cost reduction, the future of solid-state batteries looks incredibly promising and will be a game-changer for electric vehicles.

With ongoing innovation and collaboration, we are on the brink of a new era in energy storage, where the future is solid-state.

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