# Beyond Li-Ion High Energy & Power Cells Market Review 2022 (>300Wh/kg)

**December 2021**

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**Shmuel De-Leon Energy, Ltd.**
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# The battery industry is Fast Growing

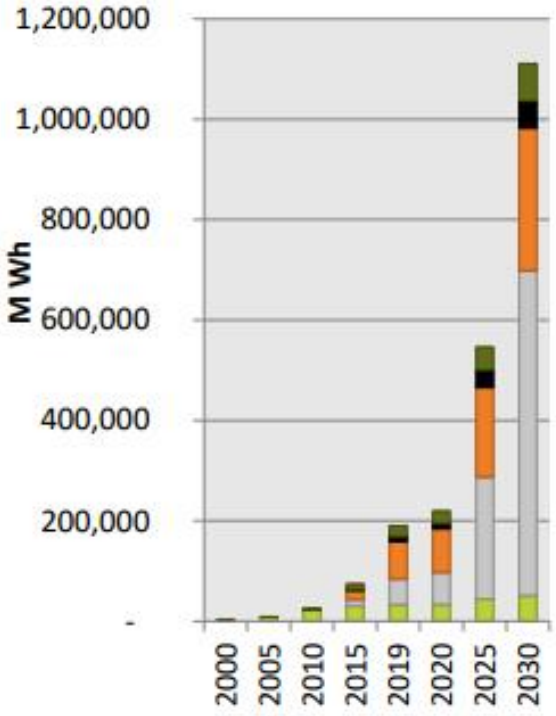
## LI-ION BATTERY MARKET FORECAST

realistic scenario

From 160 GWh in 2019 to >1,1 TWh

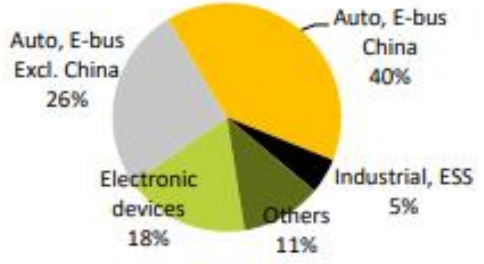
CAGR 2015/2030
+20 % per year in Volume

**Li-ion Battery sales, MWh, Worldwide, 2000-2030**

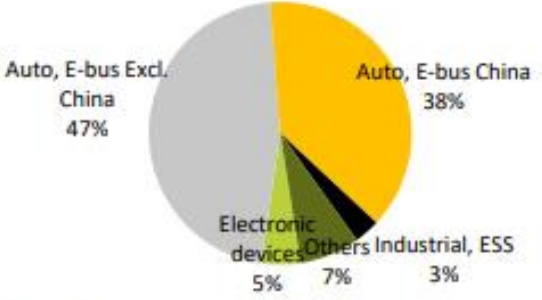



| | CAGR 15/30 (Optimistic) |
|---|---|
| Others | 14% |
| Industrial, ESS | 21% |
| Auto, E-bus China | 20% |
| Auto, e-bus Excl. China | 30% |
| Electronic devices | 4% |

**2019: >190 GWh**




**2030: >1100 GWh**




Others: medical devices, power tools, gardening tools, e-bikes...

Source: AVICENNE Energy 2020 - COVID 19 impact partially implemented as the crisis is not over - Impact could be worst

# Best Rechargeable Systems Performance in Mass Production

| | Lead Acid | NiCD | NiMH | Li-Titanate** | Li-iron Phosphate | Li-ion hard case NMC*,** | Li-ion pouch LCO*, ** |
|---|---|---|---|---|---|---|---|
| (Wh/kg) | 30-35 | 45-55 | 60-100 | 73 | 161 | 260 | 275 |
| (Wh/l) | 99 | 184 | 397 | 131 | 300 | 736 | 775 |
| Nominal Voltage | 2V | 1.25V | 1.25V | 2.4V | 3.2V | 3.5-3.8V | 3.6 – 3.8V |
| Cycle Life (to 80% of initial capacity) | 200 to 300 | 1500 | 300 to 500 | 6000 - 60000 | 1500 - 2000 | 300 to 1000 | 300 to 500 |
| Self-discharge [Month] | 5% | 20% | 30% | 3% | 3% | 1% | 1% |
| Cell Model | YUASA NPH12-12 | SANYO KR-1500AUL | SANYO HR-3U | Toshiba AP146396HA | Saft VL 45 FEE | LG INR18650 MJ1 | High Power China |

* LCO, LMO, NCA, NMC, LNM Cathodes
**Graphite/Silicon Anode, LTO Anodes

# Battery Technologies with Potential for Technology Break- Through

**Current best performance for Li-Ion cells under mass production are 275Wh/kg, 750Wh/l, 500-1000 cycles.**

**What are the future technologies with potential energy densities >300Wh/kg, 1200Wh/l**

- **Li-Ion Silicon based anode**
- **Li-Ion Solid Electrolyte**
- **Lithium metal with Sulfur/NMC cathode**
- **Li-Ion with High Voltage LCO Cathode**
- **Li-Air with lithium metal anode**

# American Lithium Energy

## Introduction to ALE 4Ah Nano 18650 Cells

- High specific energy: ~330 Wh/kg
- High power: Up to 700 W/Kg
- Excellent low temperature performance
  - >60% capacity at -40°C and at 0.2C rate
- Meet the cycle requirement of the missions 1, 2 and 4 now per Space System Commend, the US Space Force. For other missions, the testing is still on going
- Meet UN 38.03 requirement
  - Pass impact, crush, overcharge and 130°C hot box tests per UN 38.03 standard

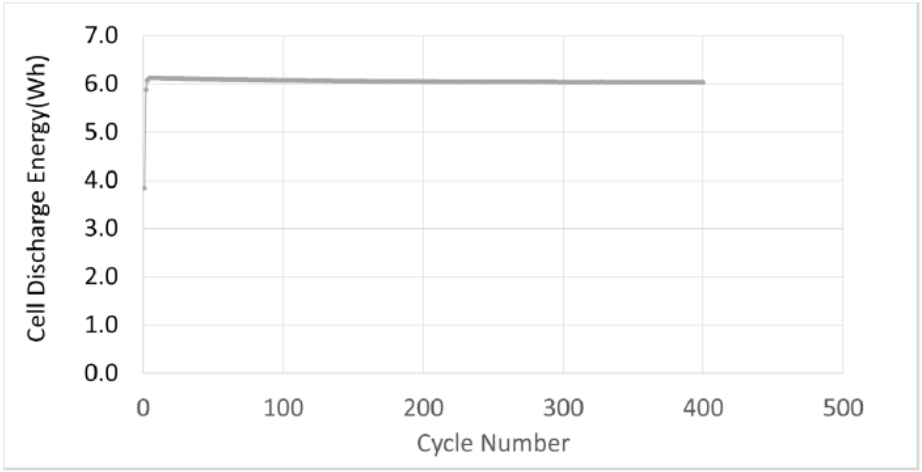
AMERICAN LITHIUM ENERGY

http://www.americanlithiumenergy.com/

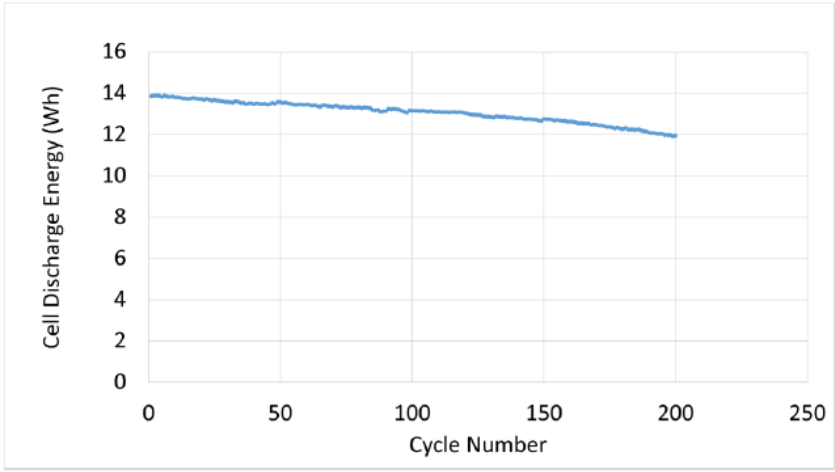
AMERICAN LITHIUM ENERGY

# Introduction to ALE 4Ah Nano 18650 Cells
## Cycle Life: 40%DOD and 100%DOD

40% DOD




100%DOD



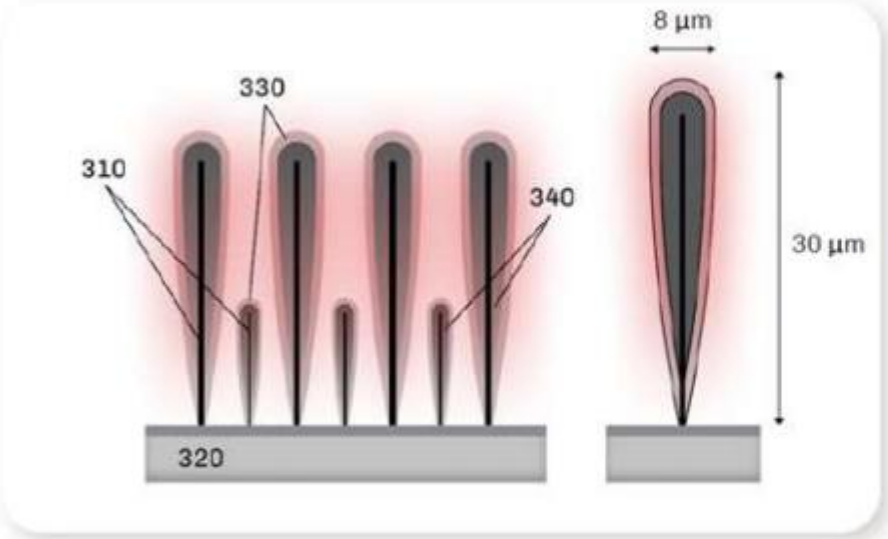

- The cycle life procedures are per S-144 requirement
- The cell energy retention is about 97.6% after 400 cycles at 40% DOD
- The cell energy retention is about 87% of its energy after 200 cycles at 100% DOD

AMERICAN LITHIUM ENERGY

# Amprius (100% Si Anode, LCO/NMC Cathode)

## THE AMPRIUS SILICON NANOWIRE ANODE SOLUTION

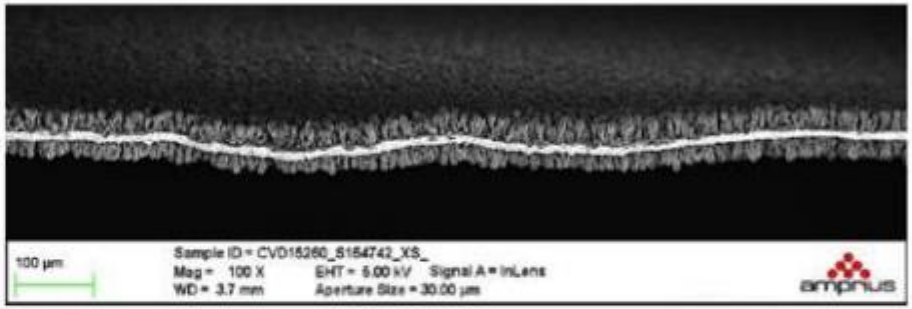
A New Structure for 100% Silicon Based on Nanowires




310 - Conductive nanowire grown from substrate

340 - Bulk coating of low density, porous amorphous silicon

330 - Thin layer of high-density amorphous silicon

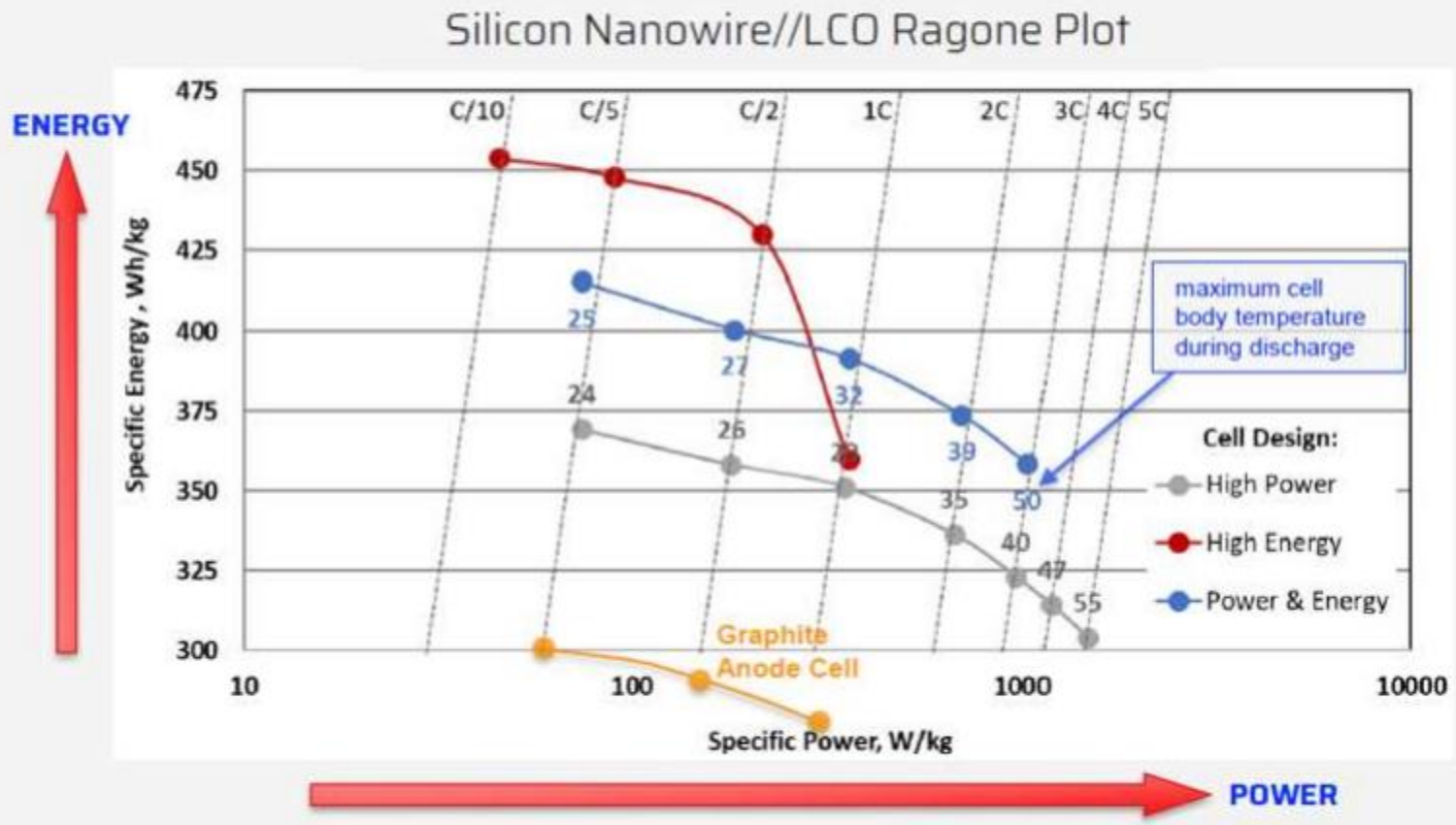



### KEY BENEFITS

- Micro & Macro porosity- solves swell problem
- Nanowire rooted mechanically and electrically continuous with substrate
- Stable Solid Electrolyte Interphase (SEI)

## HIGH ENERGY AND POWER CAPABILITY

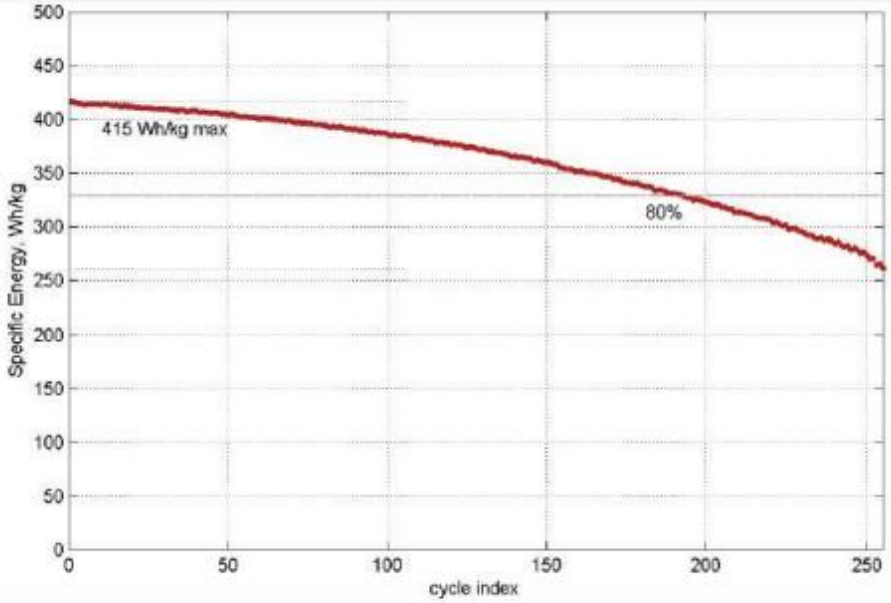
# Amprius' cells enable the highest energy and power



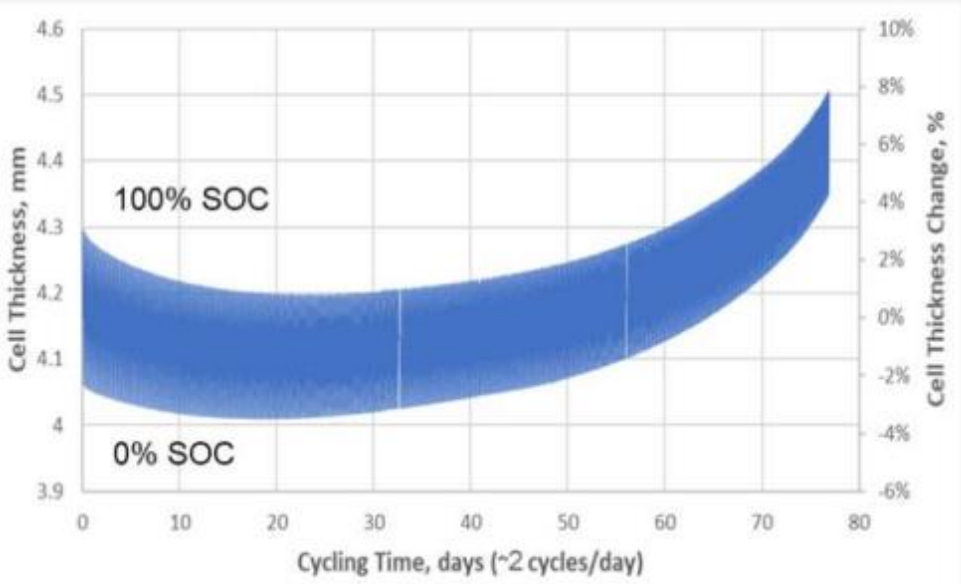
## MULTIPLE CHEMISTRIES WITH LONG CYCLE LIFE

# Long Endurance Drone Batteries

### Cycle Life with High Voltage LCO




### Cell Thickness during Cycling




Cycling at C/5 for Long Endurance UAV applications

## MANUFACTURING: ROLL-TO-ROLL FOR SILICON NANOWIRE ANODE PRODUCTION

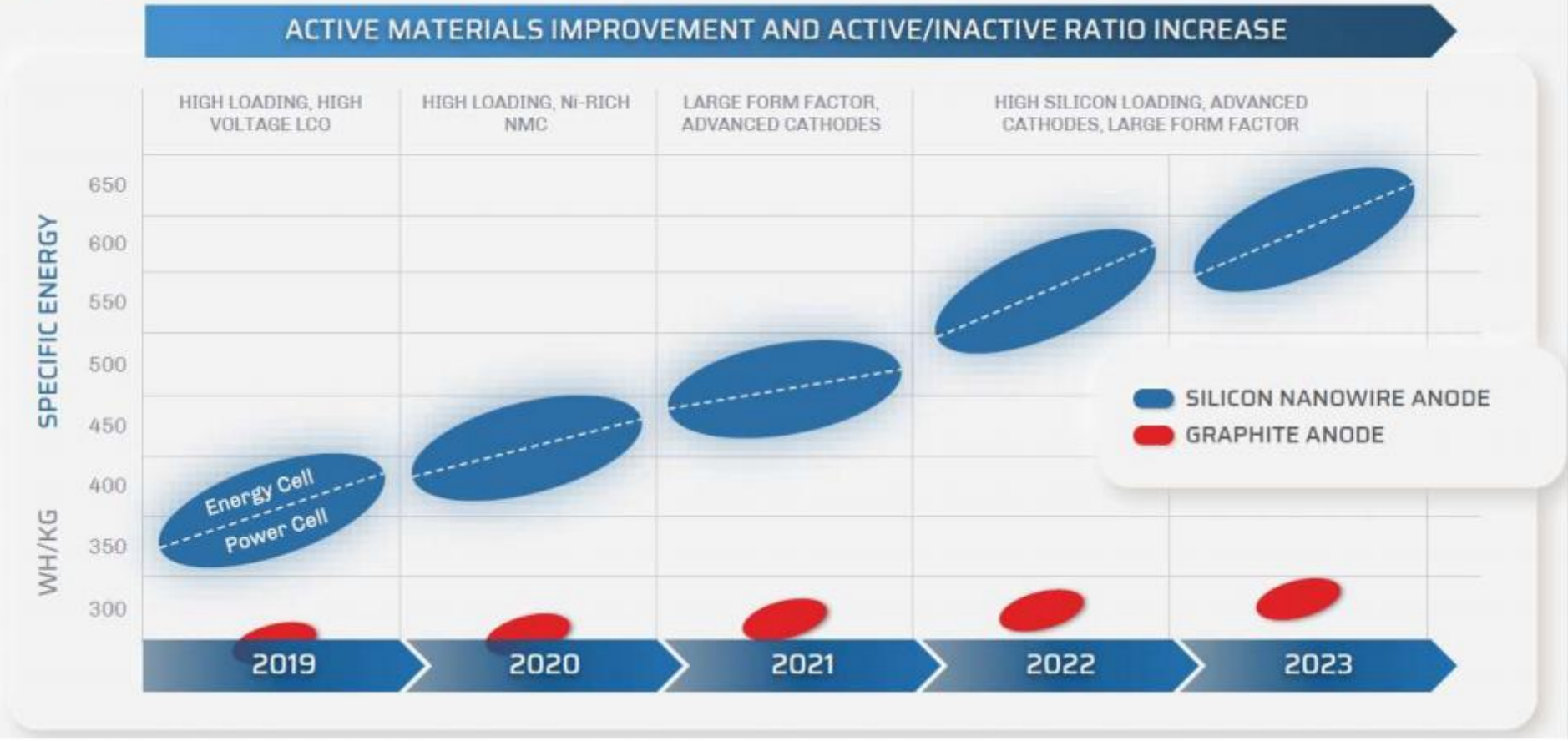
# Pilot Scale Manufacturing – demonstrated scalability with Pilot Tool

*Bare Foil In and Finished Anode Out*


**Replaces:**

- powder mixing
- slurry preparation
- roll coating (2X)
- drying
- calendaring

## ROAD MAP: SPECIFIC ENERGY



# Cuberg/Northvolt – Lithium Metal Anode with High Voltage Cathode

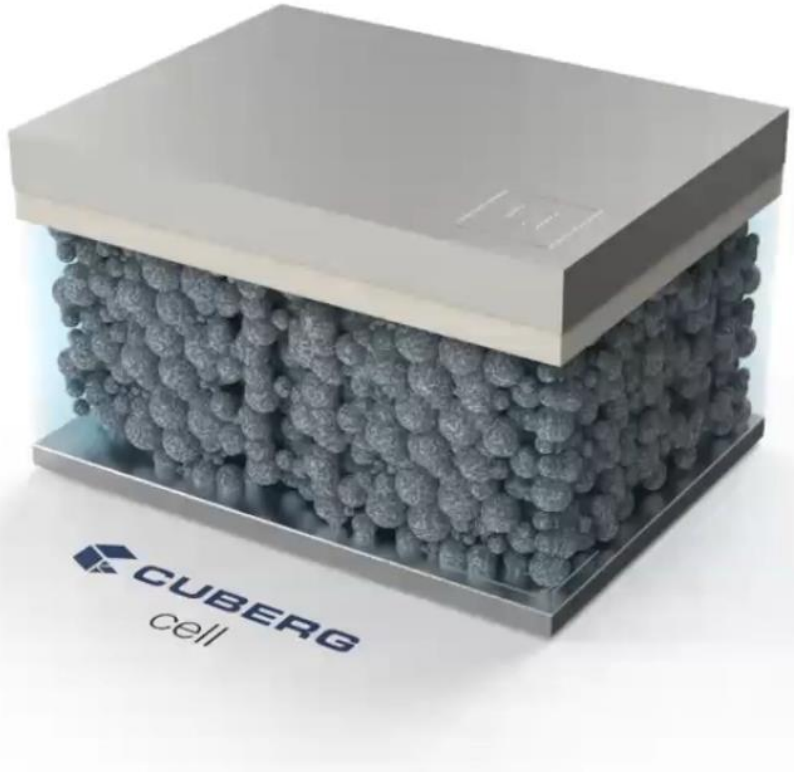

## The Cuberg cell
High-performance and scalable design

### High-performance, scalable architecture

- Energy-dense lithium metal anode, providing exceptional specific energy and power
- Proprietary non-flammable liquid electrolyte to stabilize high-energy anode and enable long cycle life
- Industry-standard Ni-rich cathode and separator

### Cuberg manufactures large-format pouch cells

- Scalable production process built on existing Li-ion battery manufacturing processes
- Step-change improvement in manufacturability compared to solid-state batteries
- Prototype samples independently validated and also evaluated by customers around the world



# CUBERG

## HV-5P (PROTOTYPE V3) RECHARGEABLE LITHIUM BATTERY

### Description

The HV Series is a next-generation battery cell that goes beyond lithium-ion to provide exceptional energy density and unprecedented safety.

Building on the success of the HT Series, this battery incorporates our proprietary and highly stable electrolyte, lithium metal anode, and high-voltage cathode for a battery that is ideally suited to replace power solutions wherever energy and stability are vital.

### Features

**Energy Improvement:** Our innovative electrolyte is electrochemically stable against commercial high-energy metal oxide cathodes, and it forms a stable passivating layer on the energy-dense lithium metal anode. This increases cell energy to 405 Wh $kg^{-1}$ and 800 Wh $L^{-1}$ – up to 80% improvements over comparable lithium-ion technology.

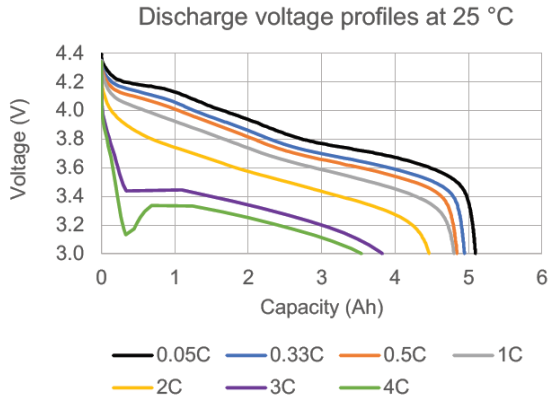
**Safety Profile:** Our new electrolyte formulation excludes organic carbonate-based solvents. The solvents and salts we use are completely non-flammable, so our cells are much less likely to smoke, ignite, or explode compared to lithium-ion cells.

**Thermal Stability:** At elevated temperatures where most rechargeable systems degrade rapidly or fail, Cuberg's battery thrives and actually delivers increased power, capacity, and longevity.

### Main Applications

- **Drones, Air Taxis, and Electric Planes**
  By using a lithium metal anode, we can make batteries light enough to power long-term electrified flight – an impossibility with lithium-ion systems. Our battery also delivers world-beating power density and abuse tolerance, allowing it to sustain even the most aggressive eVTOL conditions. Finally, the chemistry's ability to operate reliably and stably at high temperature reduces the need for pack cooling, which further increases flight time.
- **Military & Defense**
  Warfighters can move faster and talk longer equipped with our high specific energy battery. The completely nonflammable electrolyte mitigates risk of explosion or fire if the battery is punctured or otherwise damaged.
- **Ground Mobility**
  From electric cars to scooters, our batteries enable longer range and improved safety compared to lithium-ion. The technology represents a scalable and near-term solution for powering the future of electric mobility.

### Sample Data



## Product Specifications

### Size & Form

| | | |
|---|---|---|
| Form Factor | Pouch Cell | |
| Electrode Stack Dimensions | 77 x 59 x 5.3 | mm |
| Mass | 48.1 | g |
| Volume | 24 | $cm^3$ |
| Required Compression | >200 | kPa |

### Energy & Power

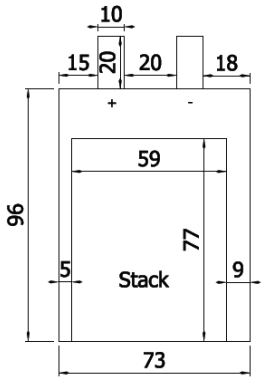
| | | |
|---|---|---|
| Cell Energy | 19.4 | Wh |
| Cell Capacity | 5.1 | Ah |
| Charge Cut-off Voltage | 4.35 | V |
| Nominal Discharge Voltage | 3.8 | V |
| Discharge Cut-off Voltage | 3.0 | V |
| Max. Constant Discharge Current | 10 | A |
| Max. 60s Pulse Discharge Current | 30 | A |
| Max. Constant Charge Current | 1.0 | A |
| DCIR (HPPC 10s Pulse) | 20 | mΩ |
| DCIR (Continuous Discharge) | 40 | mΩ |
| Nominal Energy Density | 800 | Wh $L^{-1}$ |
| Nominal Specific Energy | 405 | Wh $kg^{-1}$ |
| Max. Continuous Specific Power | 740 | W $kg^{-1}$ |
| Max. 60s Pulse Specific Power | 1,800 | W $kg^{-1}$ |

### Safety & Durability

| | | |
|---|---|---|
| Thermal Safety Limit | >130 | °C |
| Nail Penetration Test | No explosion, flames, or smoke | |
| Discharge Temperature Range | -20 to 60 | °C |
| Charge Temperature Range | -10 to 50 | °C |
| Storage Temperature Range | -20 to 45 | °C |
| Cycle Life (>80% initial capacity) | 175+ at C/6 | cycles |
| Self Discharge (25 °C, 3.8 V) | <1 | % $month^{-1}$ |
| Shelf Life (25 °C) | >15 | years |
| Calendar Life (25 °C) | >10 | years |

All specifications are provided at 25 °C unless otherwise specified.

## Cell Dimensions




The dimensions of the pouch can be customized for the specific requirements of each customer. Our standard 5-Ah cell design is 77 x 59 x 5.3 mm (LxWxH).

## Certifications

The HV series is proudly designed to comply with industry standard safety and performance certifications, including:

- UL1642
- IEC62133
- UN/DOT38.3
- MIL-STD-810G
- NAVSEA S9310

Doc. Nº 191017-01

Specifications contained herein represent projections based on current laboratory data. As research and development is ongoing, all specifications are subject to change without notice.

CUBERG

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# EoCell (High Energy Silicon + Non-Flammable Electrolyte)

## EoCell at a Glance

**Specializing In:**

- **High-Energy Nano-Silicon Anode Materials**
- **Non-Flammable Electrolyte Technologies**
- **Both for Advanced Silicon & Solid-State Batteries**

- Silicon Valley, founded in 2015
- Funded $30M by Dragon Group International (DGI) and Yinlong Energy Company (YLE) Both are active strategic partners.
- ESCN Gen 1.0 Si battery development (completed in 2019)
  : 250 Wh/Kg high energy density Pouch 48Ah and 60Ah
  : Si Gen 1.0 ( 600~900mAh/g)
- ESCN Gen 2.0 Si battery development – Under development
  : 300 Wh/Kg High energy density (Pouch 78Ah) - 4Q 2022 sample available
  : ESCN Gen 2.0 - 1300 mAh/g : sample available,
  - 1600~1800mAh/g : 1Q 2022 sample available
  : Non-flammable Electrolyte : ZAPlyte 1
- ESCN Gen 3.0 solid state battery development (400 Wh/Kg)– Under development

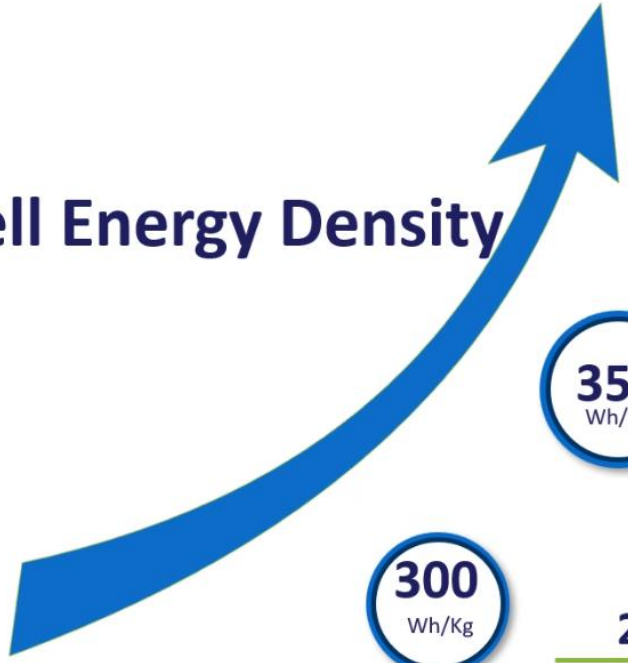
HQ in San Jose


250 Wh/Kg Pouch Cell

2

https://www.eocell.com/

# Technology Overview – Cell Roadmap



**Cell Energy Density**

Beyond **400** Wh/Kg

**2025*** **Solid-State battery (Gen 3.0)**
**+ ZAPLyte 3 Solid State electrolyte**

**350** Wh/Kg

**2023*** **Silicon Carbon Nanocomposite (Gen 2.x)**
**+ Unique Binder System**
**+ ZAPLyte 2**

Anode Electrode Capacity 800mAh/g

**300** Wh/Kg

**2022*** **Silicon Carbon Nanocomposite (Gen 2.0)**
**+ Graphite Blending Anode**

Anode Electrode Capacity 450mAh/g

**250** Wh/Kg

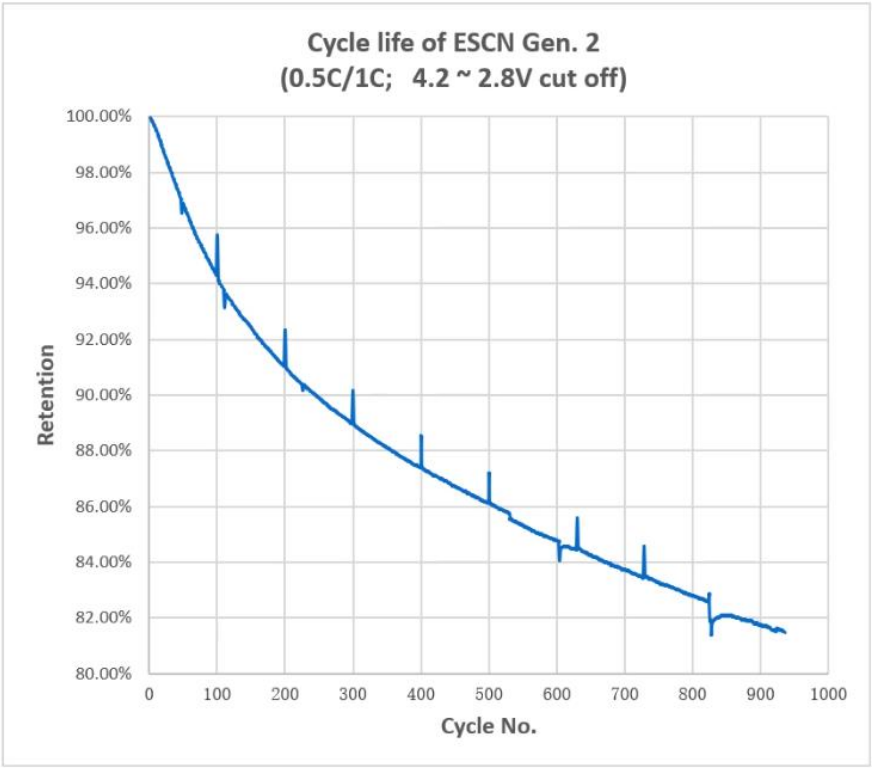
**2019*** **Silicon Carbon Nanocomposite (Gen 1.0)**
**+ Graphite Blending Anode**

Anode Electrode Capacity 400mAh/g

* End of Product Development

# 300 Wh/kg Pouch Cell (W/ESCN Gen 2) – under development

| Specifications | | Current status (A SPL Cell, Sept. '21) |
|---|---|---|
| Size (Pouch, H x W x T) including terrace | | 224*191*9.9mm |
| Weight | | 938g |
| Capacity | 1/3C (Nom.) | 77.0 Ah |
| Max. / Nominal / Min. voltage | | 4.2V / 3.60V / 2.5V |
| Energy density (Wh/kg)** | | 295 Wh/kg |
| Energy density (Wh/l)** | | 693 Wh/l |
| Cycle life (@ 0.5C/1C, DOD 100%, 25℃) | | Expected >1000 cycles |



# Enevate Corp (70% Si Anode – NMC Cathode)

## Pioneering advancements in silicon-dominant anodes leveraging accelerated battery testing & machine learning


**Pioneers** Founded 2005 in Southern California, USA

- Projected to be one of **first companies achieving next-gen silicon li-ion commercialization** going to production in 2022

**Vision** A cleaner and sustainable environment through a variety of battery powered applications and products that are accessible and affordable to everyone

**Business Model** Battery technology licensing & transfer

- Non-capital intensive, leverages experienced high volume & quality battery makers to supply the EV industry

**Technology** Developed over 10+ years with ~500 patents issued and in-process

- Tested by 20+ battery and automotive manufacturers in Asia, US, and Europe
- Licensing new 4th Generation XFC-Energy® technology with eXtreme Fast Charge for high volume commercialization


## Advantages of Enevate's patented XFC-Energy® technology for high volume commercialization

- **10X faster charging, 5-minute extreme fast charge** with:
  - **30% longer range** with energy densities of 800-1000 Wh/L
  - **100% better low-temperature performance**
  - **Safer battery** with no lithium plating
  - **Higher efficiencies** in regenerative braking & charger utilization
- **Lower cost** than today's conventional graphite Li-ion battery technology
- **Designed for existing battery manufacturing equipment and processes**
- **Delivers up to a 26% $CO_2$ greenhouse gas reduction** during manufacturing compared to conventional li-ion batteries

## Leading industry investors, partners, and customers

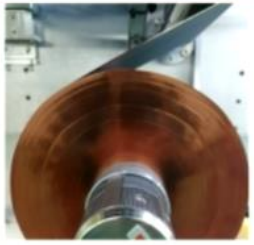
RENAULT NISSAN MITSUBISHI LG Chem Fidelity INVESTMENTS SAMSUNG ENERTECH

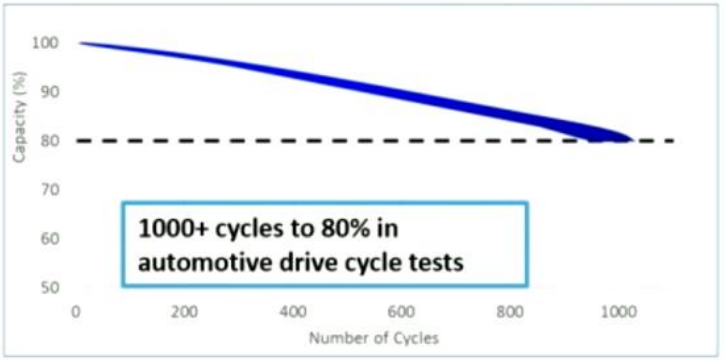
http://www.enevate.com/

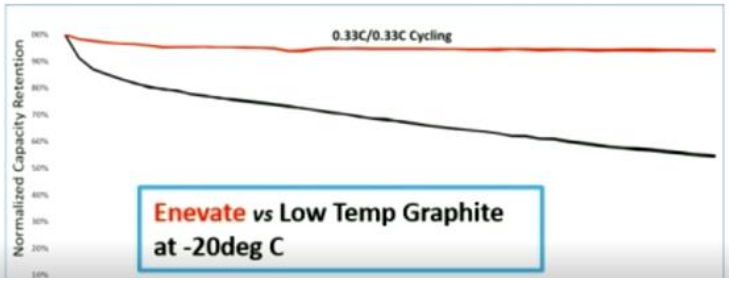
ENEVATE® Innovating Energy Storage

# Enevate 4th Generation XFC-Energy® Technology

ENEVATE






XFC-Energy Technology provides a comprehensive cell solution to the automotive industry, developed for gigafactory-scale manufacturing and lower cost than conventional Li-ion cells

- **Processes designed for high volume continuous roll-to-roll processes of over 80 meters per minute**
- **Compatible with existing factories and most cathodes**
  - **Capable of over 1000 cycles**
  - **Operation at -20˚C and below temperatures**
  - **Currently designing for 2024-2026 model year EVs**
    - 2022-2023 for other applications

# Conclusion

ENEVATE

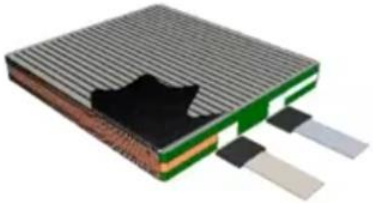
- Successfully completed large EV cell builds (30Ah – 100Ah) at multiple partners
- Actively engaged with multiple OEMs and Battery makers on Joint Development efforts.
- Licensed gateway market cell manufacturing partner
- Confirmation for 3rd party of 26% lower carbon emissions (LCA)
- Confirmation of enhanced battery safety: nail penetration test results
- Total number of patents now at ~500
- Accelerating implementation of new expanded Enevate line at new Irvine location by 2H2022


Accelerating enhancements in next gen battery technology to commercialization

# Enovix (100% Si Anode, LCO Cathode)

## Enovix 3D Silicon™ Cell Architecture

**Enovix 3D Silicon** Lithium-ion Cell



**Photomicrograph Cross-Section**[1]

**Silicon Anode Material Capacity**

**1800 mAh/cc**[2]

Conventional **Wound** Lithium-ion Cell

**Illustrated Cross-Section**

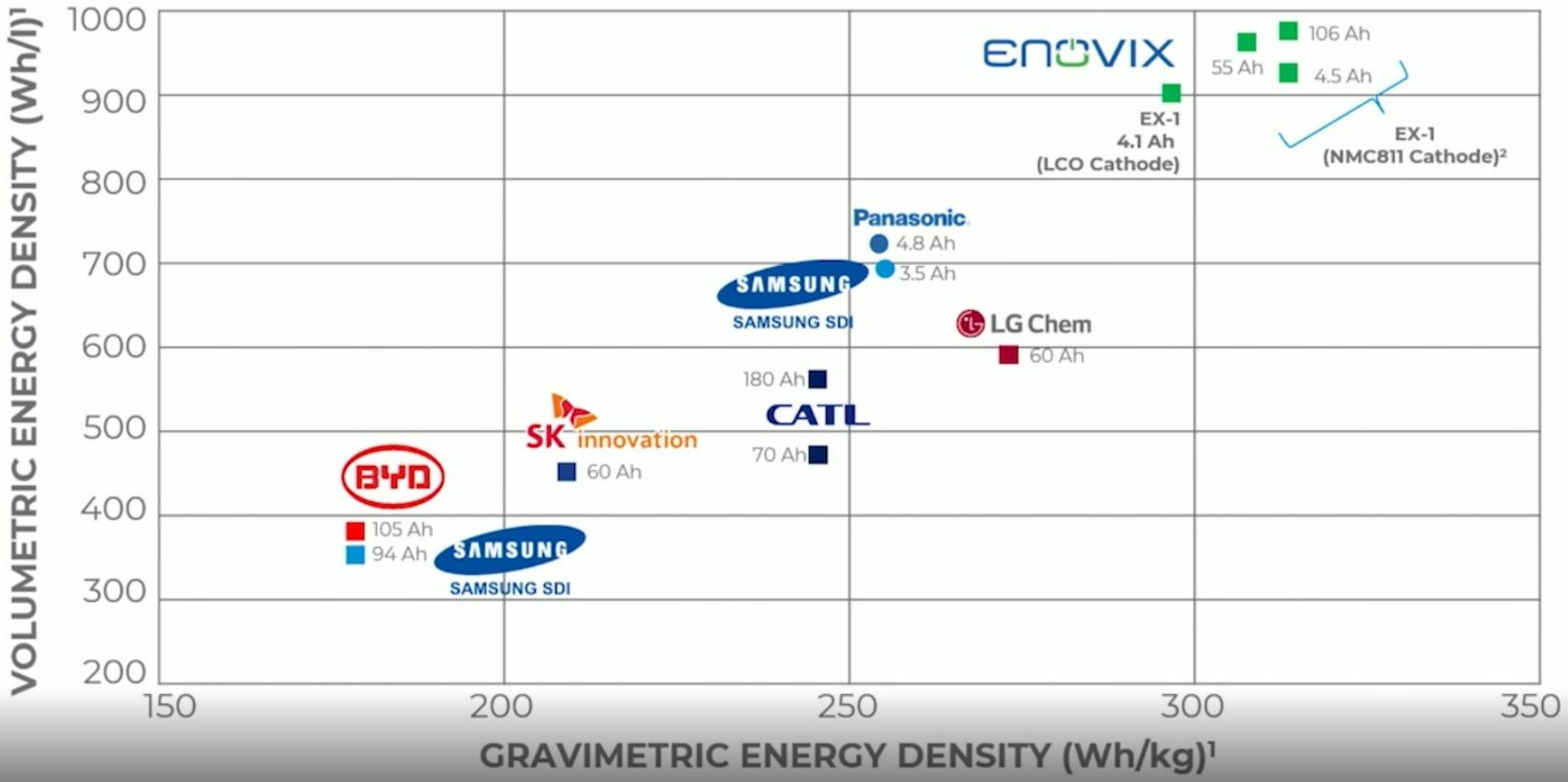
**Graphite Anode Material Capacity**

**800 mAh/cc**[3]

[1]Source: Enovix Corporation. [2]De-rated from theoretical capacity of 2194 mAh/cc for Li trapping losses

http://www.enovix.com/

# The Leader in Energy Density






[1] Sources for competitor data: UBS Global Research, October 2020 and Samsung data sheet (Model INR18650-35E) [2] Design Targets

# Commercialization Roadmap
## PROJECTED

| 2022 | 2023 | 2024 | 2025 |
|---|---|---|---|


**Fab 1**
254 MWh Capacity
Q2 2022 First Revenue
2025E Units: 45M

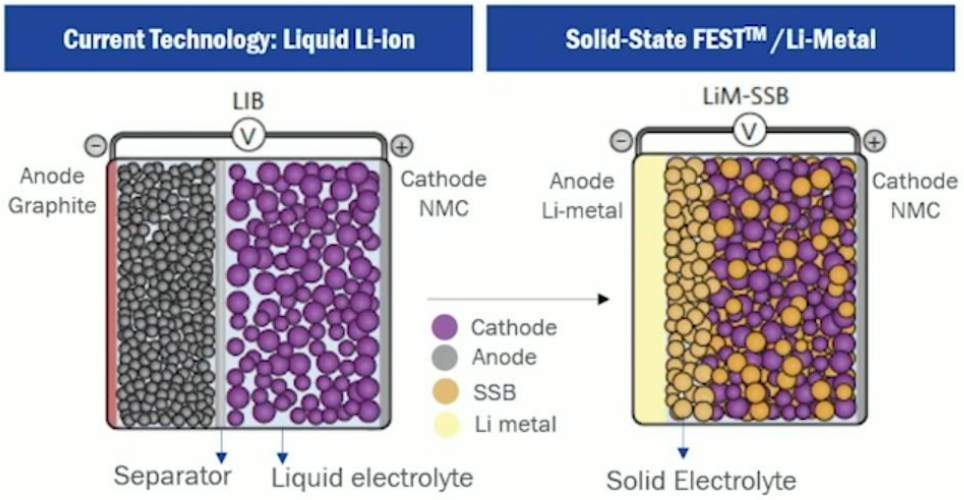
**Fab 2**
1.53 GWh Capacity
Q2 2023 First Revenue
2025E Units: 89M

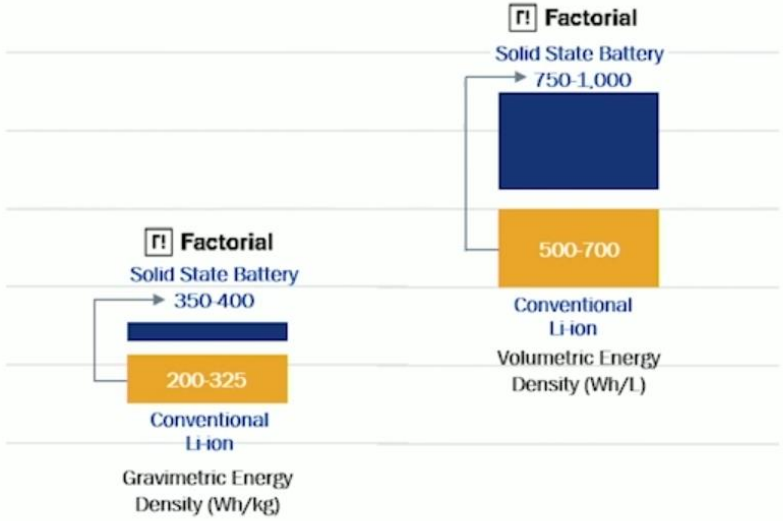
**Fab 3**
Auto JV or Licensing
2025 First Revenue

# Factorial (Lithium Metal Anode, Solid Electrolyte)

## Factorial's Unique Technology to Deliver Significant Outperformance

Factorial Electrolyte system technology (FEST™) delivers on more demanding OEM battery requirements



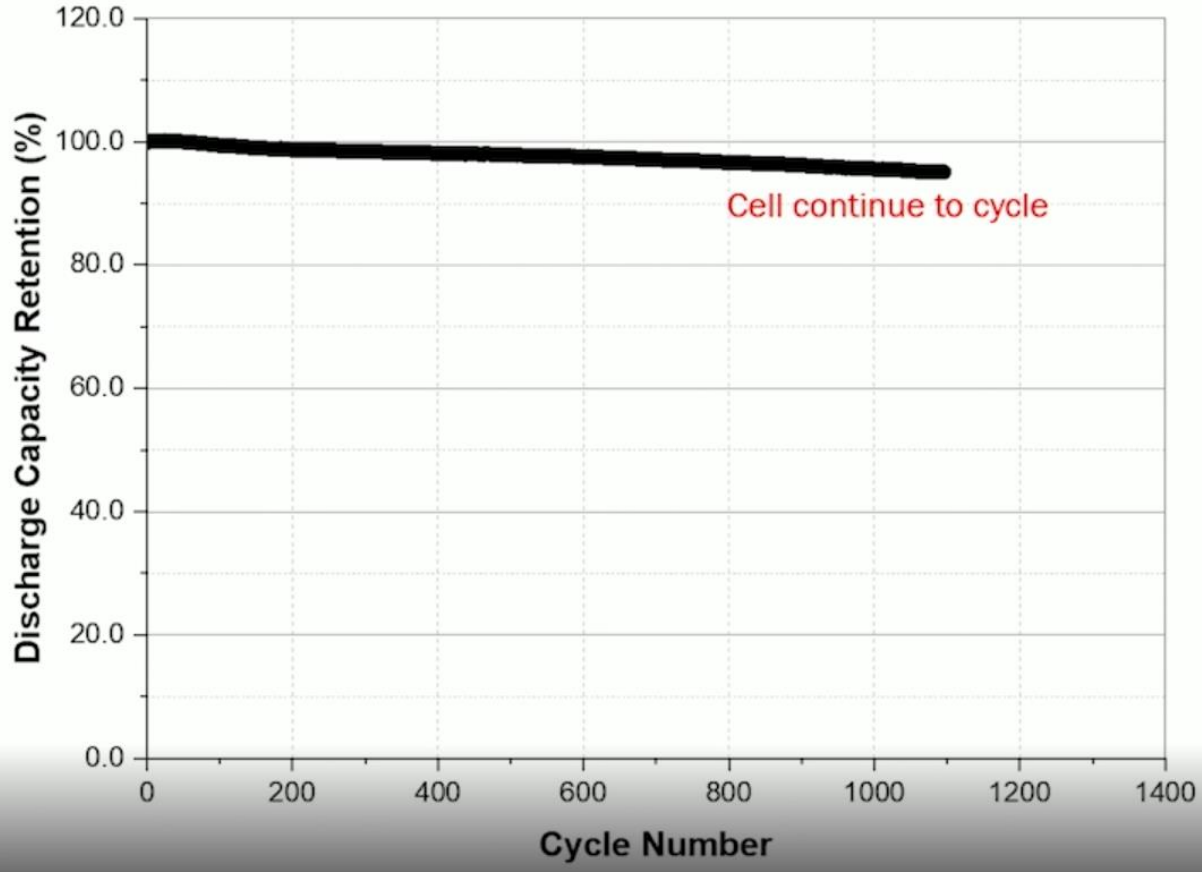




- **Safe electrolyte:** Conventional liquid electrolyte has flashing point of ~60-70°C, while Factorial Electrolyte System Technology - FEST™ is not flammable until at least 200°C
- **The most flexible system adapting to the high energy density design:** Compatible with both high capacity cathode and anode materials (cathode: 811/NCA, anode: lithium metal / silicon), to provide high energy density battery solution for future EVs
- **Easy to scale up** with strong cost competitiveness to conventional Li-ion, mitigated risk in capex investment
- **Drop-in replacement** of existing battery manufacturing process

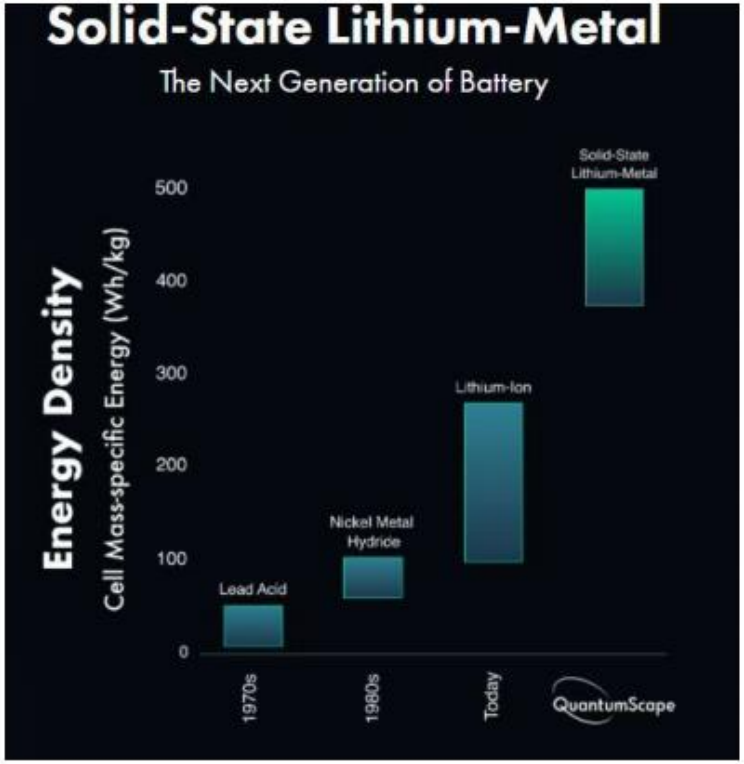
Source: Jürgen Janek, et al., Nature Energy 2016, company information.

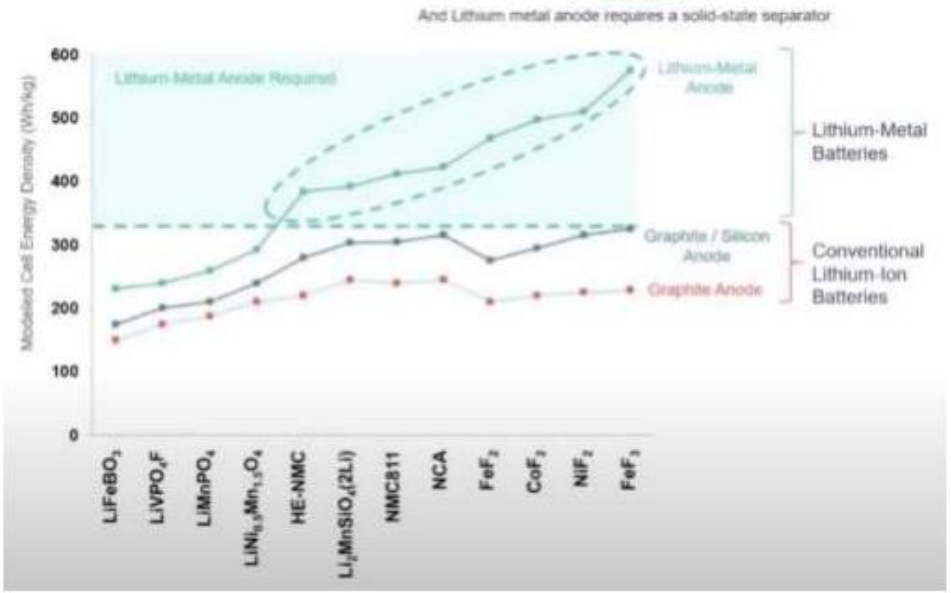
# Large Format NMC811/Graphite Cell (40Ah) at Room Temp

40Ah Pouch Cell cycling : 4.2~2.8V, 0.33C/0.5C Cycle (25°C)



# QuantumScape (Lithium Metal Anode, Solid Electrolyte)




Lithium-metal anode necessary to achieve high energy density

Lithium-metal cannot be used without a solid-state separator

QuantumScape

https://www.quantumscape.com/

# QuantumScape Zero Li Anode-free Architecture

Improved cost, energy density, safety

## Conventional Li-ion Battery


## QuantumScape Solid-State Battery

Discharged
(as manufactured)

Charged


1 **Anode-free Manufacturing**
Anode-free cell design with lithium plated during charge cycles

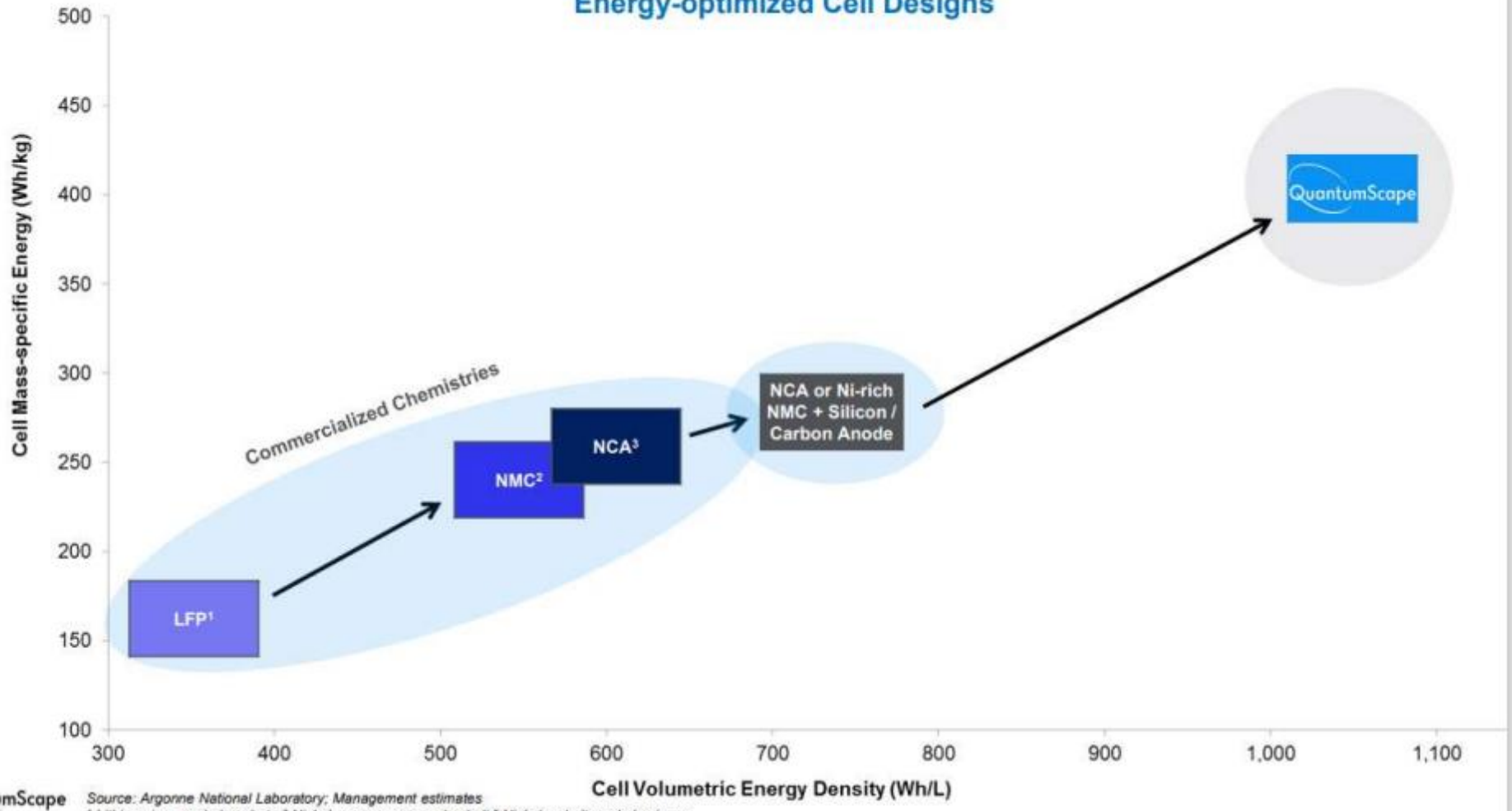
2 **Solid-State Separator**
Ceramic electrolyte with high dendrite resistance

3 **Lithium-Metal Anode**
High-rate cycling of a lithium-metal anode

QuantumScape

# QuantumScape is a Step-Function Ahead of Conventional Cells

## Energy-optimized Cell Designs

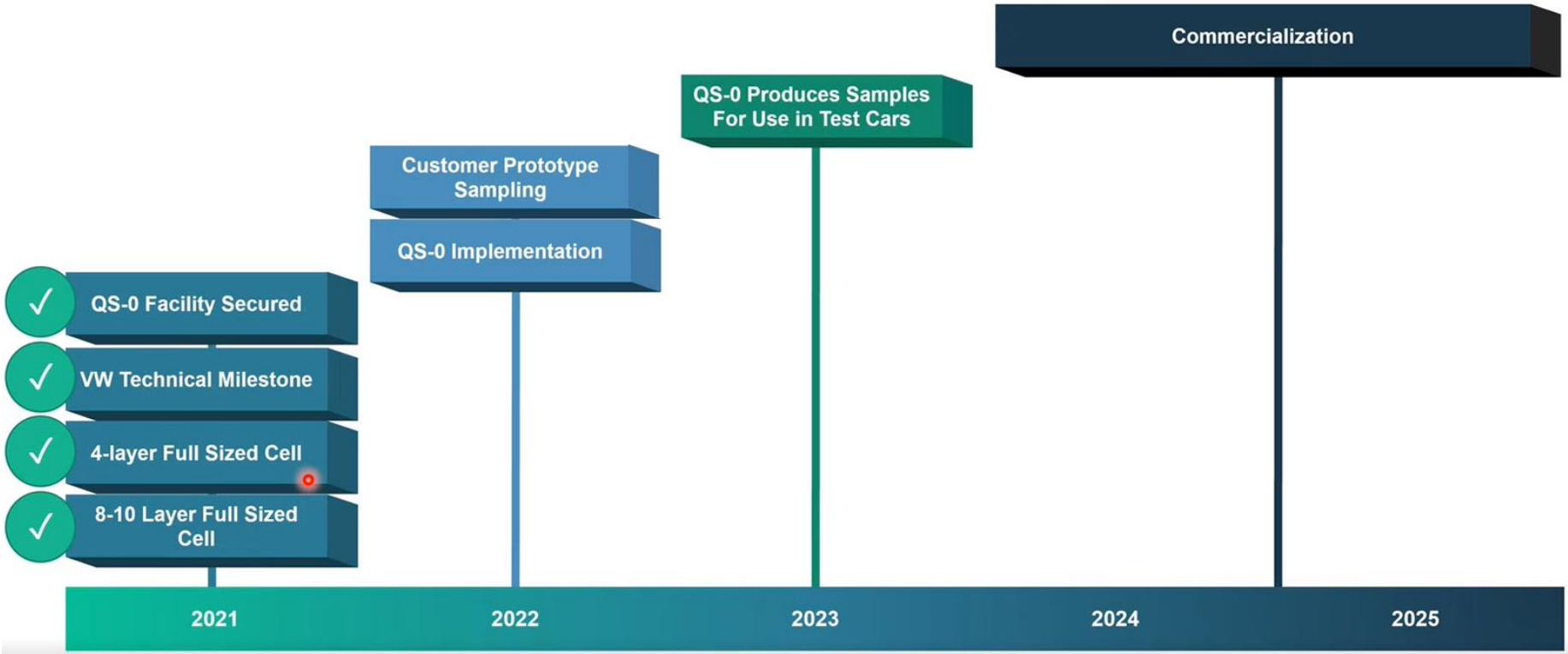



QuantumScape

*Source: Argonne National Laboratory; Management estimates*

*¹ Lithium, iron, and phosphate ² Nickel, manganese, and cobalt ³ Nickel, cobalt, and aluminum*

# Key Milestones




QuantumScape

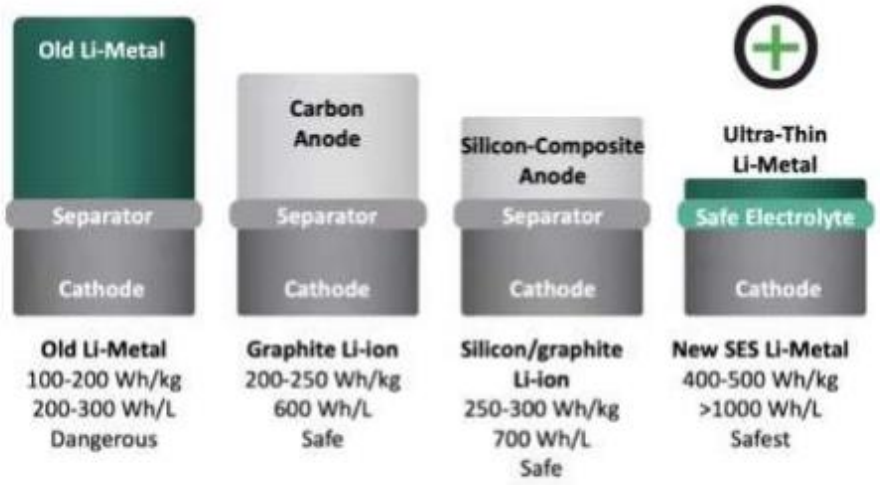
# Solid Energy (Li Anode + Liquid Electrolyte + NMC)

solid energy

SolidEnergy Systems

Beyond Li-ion™

## SES has Made Fundamental Li-Metal Technology Breakthroughs




**Old Li-Metal**
100-200 Wh/kg
200-300 Wh/L
Dangerous

**Graphite Li-ion**
200-250 Wh/kg
600 Wh/L
Safe

**Silicon/graphite Li-ion**
250-300 Wh/kg
700 Wh/L
Safe

**New SES Li-Metal**
400-500 Wh/kg
>1000 Wh/L
Safest

### Materials

Leading proprietary technologies, strong IP portfolio and manufacturing capabilities in thin lithium foil anode and high purity lithium salt and electrolyte. Addressing lithium dendrite growth issue without compromising cell performance, manufacturability and cost

### Cells

The world's leader in Li-Metal cells design, engineering and manufacturing. Largest data pool with extensive testing conditions for Li-Metal cells. Capable of passing UN38.3, UL1642, IEC62133, PSE and nail penetration, world's first for >400 Wh/kg cells

### Packs & Modules

Leader in Li-Metal modules and packs covering mechanical, thermal and electrochemical capabilities. Largest data pool with extensive testing conditions for Li-Metal modules and packs

### AI Powered BMS

Leading Li-Metal BMS. The first to integrate machine learning, AI and deep fundamental physical understanding for Li-Metal. Health monitoring and safety prediction tool can be used for both Li-Metal and Li-ion

### Recycling

Leader in Li-Metal recycling with proprietary technologies for recycling cycled mossy lithium anode to fresh lithium compound to ensure long term sustainability

# Hermes™

## High Energy Rechargeable **Metal Cells**

### Benefits

- World's lightest **rechargeable** battery
- High volumetric energy Density of 725 Wh/L
- The ultra-high gravimetric energy density of 400Wh/kg
- High Voltage
- Flexible, customizable design
- Recommended for weight constraint applications

### Key Features

- Excellent capacity retention and long cycle life
- High pulse charge rate
- High continuous discharge rate
- Great high-altitude performance
- Practical operating temperature range
- High cycling efficiency

### Main Applications

- High-altitude drones
- Commercial drones
- Electric autonomous flying transportation
- Consumer electronics
- Power tools
- Small UPS
- Transportation

### Hermes™ Cell Life

SES developed advanced high-energy lithium-metal (Li-Metal) rechargeable battery technology, which delivers best-in-class energy density characteristics and cycling performance. This product is ideally suited for applications requiring very high gravimetric and volumetric energy densities that have battery-weight and dimension constraints, such as aeronautics and space, consumer electronics, EVs, and eVTOLs.

#### Electrical Characteristics

| | |
|---|---|
| Nominal Voltage | 3.82 V |
| Typical Capacity (C10, 25°C) | 3.75 Ah |
| Nominal Energy | 14.32 Wh |

#### Mechanical Characteristics

| | |
|---|---|
| Height | 71.5 ± 1.0 mm |
| Width | 48.5 ± 1.0 mm |
| Thickness | 5.7± 0.3 mm |
| Typical Weight | 36 g |
| Cell Volume | 0.02 L |

#### Operating Conditions

| | |
|---|---|
| Charge Method | Constant Current / Constant Voltage |
| Charge Voltage | 4.25V |
| Maximum Recommended Charge Current | 0.75 A (0.2 C Rate) |
| Charge Temperature Range | 0°C to 45°C |
| Charge Time at 25°C | Function of the Charge Current<br>C Rate → 1.5 – 2 Hr<br>C/2 Rate → 2.5 – 3 Hr<br>C/5 Rate → 6 – 7 Hr |
| Maximum Continuous Discharge Rate | 11.2 A (3C Rate) |
| 1kHz ACR, Ω (30%SOC, RT) | <15 mΩ |
| Pulse Discharge Rate | Up to 37.5 A (10C Rate) |
| Discharge Cut-off Voltage | 3 V |
| Discharge Temperature Range | -10°C to 45°C |

*Electric protection circuits within battery packs may limit the maximum charge/discharge current available. Contact SES.

# Current Status vs. OEM 2025 Targets

| OEM 2025 Targets | SES Current Status |
|---|---|
| **Energy Density: >400 Wh/kg, >1000 Wh/L** | ✓ Already demonstrated 376 Wh/kg in 3.35 Ah prototype cells, and project >400 Wh/kg and >1000 Wh/L when scaled up to 100 Ah EV cells |
| **Lifetime: 500 cycles until 80% capacity retention** | ✓ Already demonstrated Li-Metal chemistry can achieve 600 cycles until 80% capacity retention. 3.35 Ah prototype cell can achieve 500 cycles at C/10 charge and C/3 discharge at 23°C |
| **Fast Charge: 15 min 0 → 80%** | ✓ Already demonstrated 12 min from 10% to 80% state of charge in 3.35 Ah prototype cells |
| **Cobalt Amount: <7wt% or <11mol%** | ✓ All cathodes used in SES prototype and future EV cells have low Cobalt. SES is open to using OEM recommended cathode |
| **Safety: Hazard Level <=4** | ✓ 3.35 Ah prototype cells passed external short circuit, thermal stability, overcharge, ARC, and nail penetration |

# Solid Power (Li Anode + Solid Electrolyte)

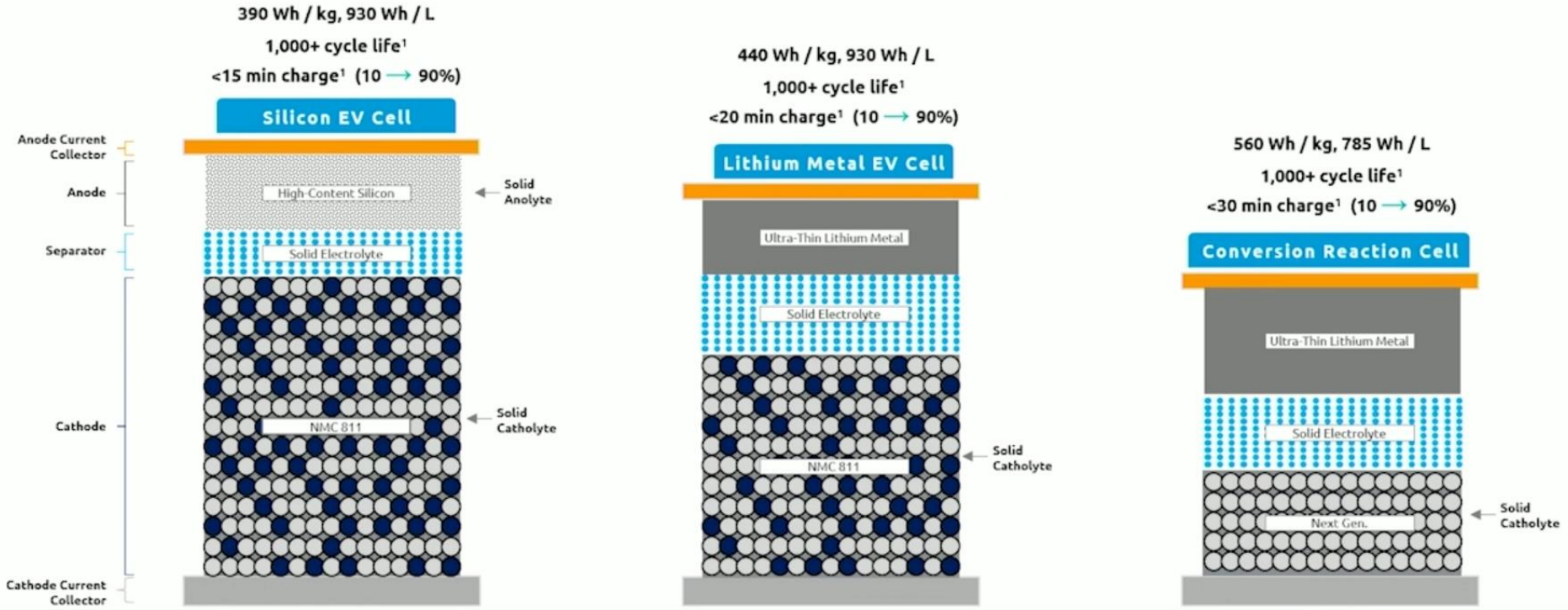
- Solid-state is a practical approach to improving energy density and safety in parallel
- Enabling Li metal is key to reliable long life, but cathode design is also key for maximizing performance
- Challenges remain in minimizing passive mass and volume, accommodating volume changes, and improving rate capability at low temperatures
- Opens up the design space with new materials and cell and battery concepts to ensure continued energy density gains for electric vehicle batteries

Solid Power

https://solidpowerbattery.com/

# Solid Power Product Roadmap

Sustaining a product roadmap with continuous performance improvements across three unique chemistries




**Multi-product roadmap specifically geared to satisfy Auto OEM objectives of early and sustained success**

Note: Lithium metal anode portrayed in the fully-charged state. Solid Power cell performance metrics are initial commercialization design targets.1. Solid Power estimates.

# Real Results on the Path to Commercialization

## Rapid performance and manufacturing achievements

**0.2 Ah**

2019

1-Layer, 5 x 10 cm Cell

**2 Ah**

2020

10-Layer, 5 x 10 cm Cell

**20 Ah**

2020

22-Layer, 9 x 20 cm Cell

**100 Ah**

2022

2024[2]

EV Cell Line Under Construction
Cell Production Expected in 2022

**Independently tested by Auto OEMs, top tier battery manufacturers and material suppliers[1]**

Note: Lithium Metal EV Cell pouches shown for 0.2 Ah, 2 Ah, and 20 Ah. Each cell layer refers to the number of double-sided cathodes. 1. Independent testing completed for 0.2 Ah and 2 Ah cells to date with 20 Ah independent testing pending. 2. Cell rendering shown for 100Ah cell. 100 Ah Silicon EV Cell anticipated in 2022. 100 Ah Lithium Metal EV Cell anticipated in 2024.

# Nextech Li-S Cells

***NexTech's product is market ready***

- NexTech has two battery designs:
  - HE Cell: Optimized for High Energy
    - Stable, high-energy cathode
    - Wh/kg (400-500 Wh/kg) vs Li-ion (300 Wh/kg)
    - Cycle life competitive with current Li-ion
  - HP Cell: Optimized for High Power
    - Advanced cathode active materials that delivers higher power
    - ~6 C-rate capable
    - Higher cycle life
- Innovative and simplified manufacturing approach
  - Dramatic reduction in binder use vs. Li-ion
  - Semi-automated pilot plant with capacity of >10,000 cells/year

| | NexTech HE Cell | NexTech HP Cell | Panasonic NCR21700 |
|---|---|---|---|
| Composition | Li-S Pouch | Li-S Pouch | Li-Ion Can |
| # of Electrodes | 21 | 21 | jelly roll |
| | | | |
| Nominal Cell Voltage (V) | 2.1 | 2.1 | 3.6 |
| Max Cell Voltage (continuous) (V) | 2.5 | 2.5 | 4.2 |
| Max Cell Voltage (pulse) (30s) (V) | 2.8 | 2.8 | n/a |
| Min Cell Voltage (continuous) (V) | 1.8 | 1.8 | 2.5 |
| Min Cell Voltage (pulse) (30s) (V) | 1.5 | 1.5 | 2.5 |
| | | | |
| Max. Peak Discharge (10s) (C-rate) | 3 | 6 | 1.9 |
| Max. Peak Discharge (30s) (C-rate) | 3 | 3 | Fails |
| Max. Continuous Discharge (C-rate) | 1 | 3 | .3 |
| Max. Charge Rate (C-rate) to 80% SoC | 2 | 3 | .7 |
| Opt. Charge Rate (C-rate) | 0.2 | 0.2 | 0.3 |
| | | | |
| Cycle Life (Projected cycles @ 50% DoD) | 1,000 | 1,500 | 1,000 |
| Cycle Life (Projected cycles @ 80% DoD) | 600 | 1,000 | 800 |
| Cycle Life (Projected cycles @ 100% DoD) | 300 | 600 | 300 |
| | | | |
| Operating Temperature (°C) | -40 to +70 | -40 to +70 | 0 to +50 |
| Storage Temperature (°C) | -40 to +70 | -40 to +70 | -20 to+ 45 |
| | | | |
| Specific Energy @0.1C (Wh/kg) | **420** | **330** | **240** |


NexTech Batteries

# Sion Power (Li-Metal)

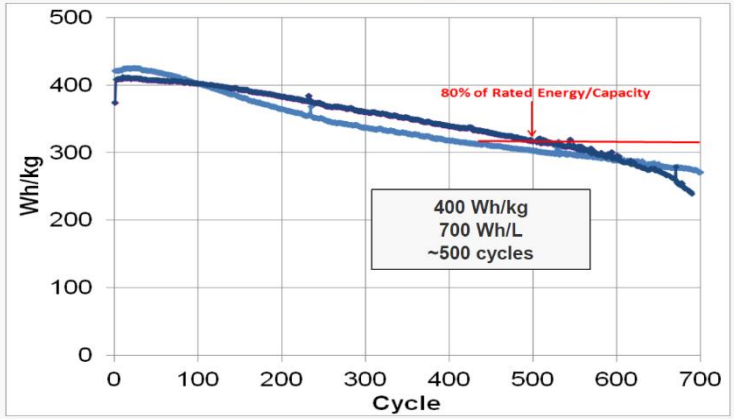
## *Licerion*® Topics

LICERION® by SION POWER®

- Sion Power's new *Licerion*® technology as a solution beyond Li-Ion and beyond Li-S.
  - Failure mechanisms of rechargeable batteries with metallic lithium anode.
  - Failure mechanisms addressed with *Licerion*® technology.
- Sion Power development of *Licerion*®-S and *Licerion*®-Ion batteries.
  - Li-S and *Licerion*®-S for Unmanned Aerial Vehicles (UAV).
  - *Licerion*®-Ion for diverse applications.

## *Licerion*®-Ion Offers Highest Combination of Specific Energy and Longest Cycle Life

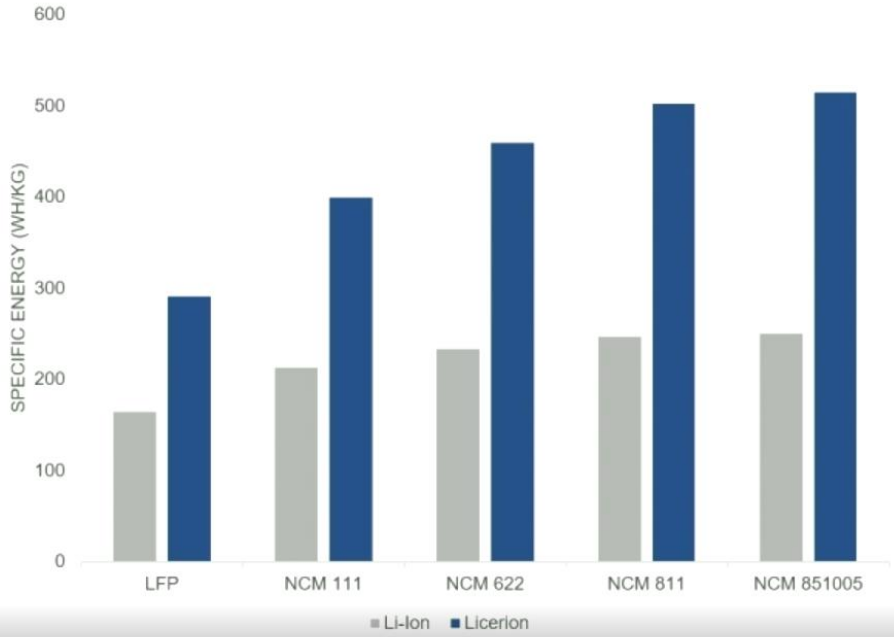
LICERION® by SION POWER®




Specific Energy and Energy Density projected to 10x10x1cm large cell design using same active materials balance as laboratory 0.4 Ah cells and accounting for weight and volume of all large cell components.

# Licerion® Lithium Metal Anode Enables High Energy

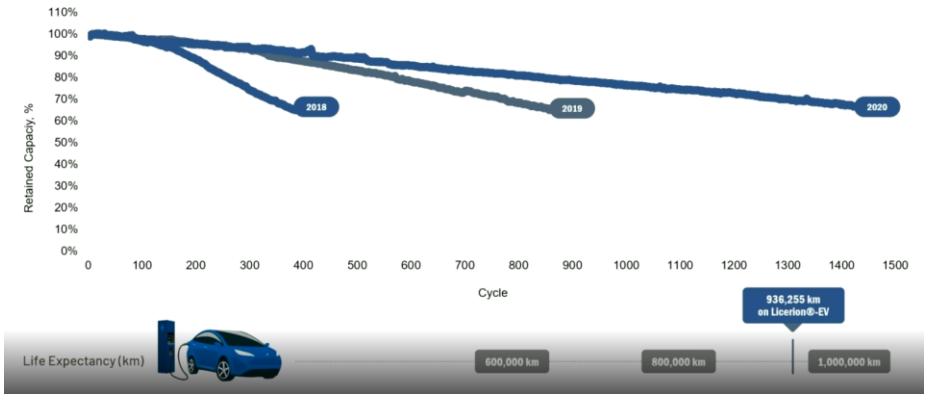
Versatility to meet a wide range of applications




LFP = Lithium Ferro Phosphate, NCM = Nickel Cobalt Manganese

- Licerion Lithium Metal Anode Doubles the Energy of Today's Common Market Cathode Materials
- Licerion can be Paired with Any Known Cathode Material and Retain that Material's Desirable Character
  - Safety
  - Cycle Life
  - Power

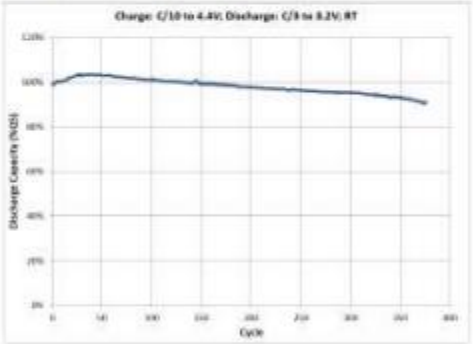
## Licerion® Projected to Exceed Future Automotive Battery Life Requirements



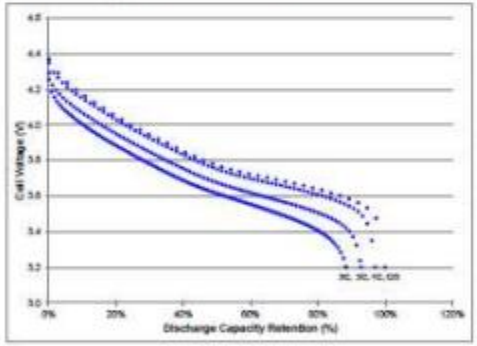
# Licerion® Cell Technical Specifications

| Electrical Specifications | 20 Ah (No. CL-B1010-20) | 10 Ah (No. CL-B1010-10) | 6 Ah (No. CL-B1010-6) |
|---|---|---|---|
| Nominal Voltage | 3.8 V | 3.8 V | 3.8 V |
| Typical Capacity, C/3 20°C | 19.8 Ah | 10.2 Ah | 5.4 Ah |
| Nominal Energy | 76.2 Wh | 39.2 Wh | 20.8 Wh |
| **Physical Characteristics** | **20 Ah** | **10 Ah** | **6 Ah** |
| Length | 100 mm | 100 mm | 100 mm |
| Width | 100 mm | 100 mm | 100 mm |
| Thickness | 10 mm | 4.27 mm | 3 mm |
| Cell Volume | 100 mL | 53 mL | 30 mL |
| Weight per Cell | 154 g | 82 g | 46 g |
| **Operating Conditions** | **20 Ah** | **10 Ah** | **6 Ah** |
| Charge Method | Constant Current, Constant Voltage | Constant Current, Constant Voltage | Constant Current, Constant Voltage |
| Charge Voltage | 4.4 V | 4.4 V | 4.4 V |
| Max. Recommended Charge Current (Rate) | 6.6 A (C/3 Rate) | 3.4 A (C/3 Rate) | 1.8 A (C/3 Rate) |
| Temperature Range | -20 to 45°C | -20 to 45°C | -20 to 45°C |
| Max. Continuous Discharge Current (Rate) | 60 A (3C Rate) | 30 A (3C Rate) | 16 A (3C Rate) |
| Pulse Discharge Rate (5s) | Up to 100 A (5C Rate) | Up to 50 A (5C Rate) | Up to 27 A (5C Rate) |
| Discharge Cut-off Voltage | 3.2 V | 3.2 V | 3.2 V |

Cell Cycle Life Characteristics




Cell Discharge Rate Characteristics




**Safety, Storage, and Handling**

Licerion is a rechargeable, lithium metal battery cell containing a large amount of energy concentrated in a small volume. Appropriate precautions must be observed during handling and use of lithium based cells including:

- Do not disassemble or incinerate; dispose according to state and federal regulations
- Do not short terminals
- Store and use batteries in temperatures below 45°C and above -40°C
- Wear personal protective equipment (PPE) when handling lithium-based cells and batteries

# The **Licerion®** Advantage

## Licerion is a Total Energy System

Cells, modules, and battery
management system working together

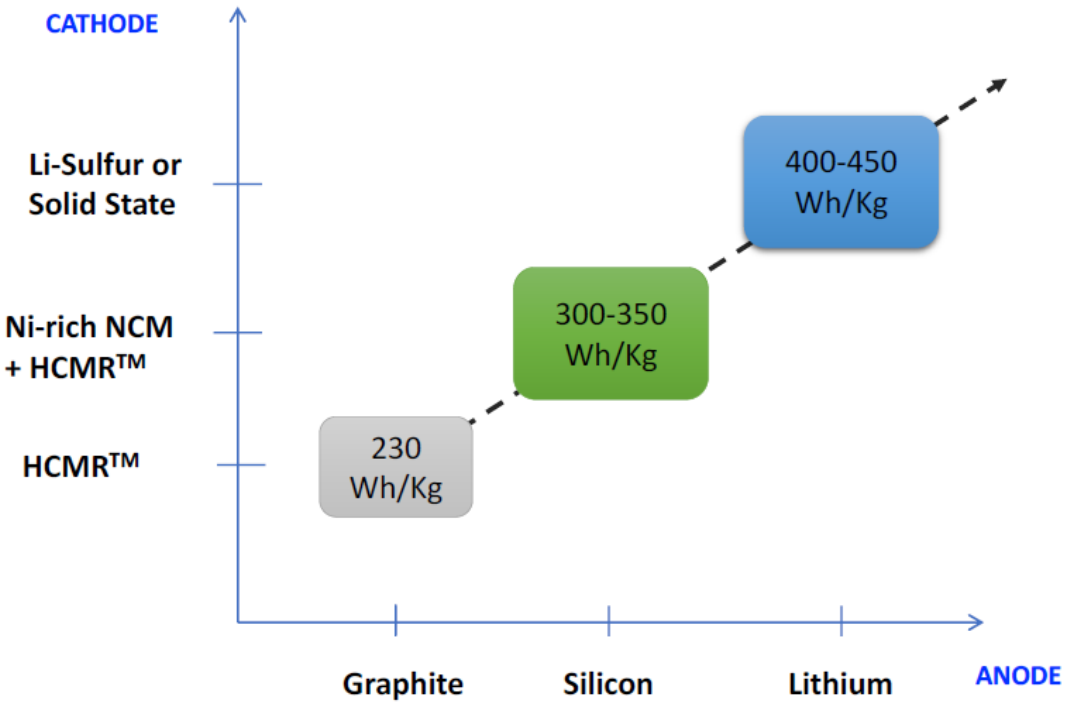

- ✓ **High Energy per Unit Mass**
  Resulting lighter vehicle leading to greater range, faster acceleration, better handling, and reduced cost
- ✓ **Fast Charging**
  Demonstrated fast-charge capability, no external heating required
- ✓ **Safety Focused**
  Redundant chemical, physical, and mechanical protection to effectively eliminate lithium dendrites
- ✓ **High Power**
  Cells are engineered to exceed standard automotive power requirements – independent of temperature
- ✓ **Long Cycle Life**
  Exceeds auto industry requirement of 800 cycles
- ✓ **High Battery Capacity**
  Demonstrated single cell capacity up to 20 Ah; no known limitations on even higher capacity
- ✓ **Versatility**
  Can be paired with a variety of cathodes
- ✓ **Broad Temperature Range**
  Charges and discharges well at low or high temperatures eliminating need for external heating

# Zenlabs Energy (Former Envia)


Silicon anode development for high energy long cycle life lithium ion cells

https://www.zenlabsinc.com/

# Cell Technology Roadmap




- 230 Wh/Kg was achieved in 1st USABC program using Lithium Rich Manganese rich Cathode (HCMR™)
- Development of >300 Wh/Kg batteries is ongoing in 2nd USABC program
- 350 Wh/kg – 300 cycles cells are being commercialized for drone applications

zenlabs

zenlabs

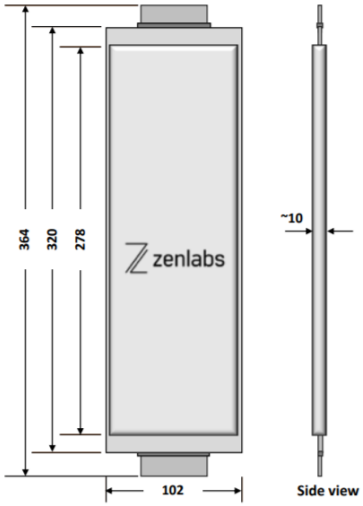
# *High Energy EV Pouch Cells*
*(Range EV Cells)*

## *Key Features & Benefits:*

✓ High usable energy to 100% SOC
✓ High capacity $SiO_x$ anode paired with NCM cathode
✓ Exceptional power and high rate capability
✓ Low cost

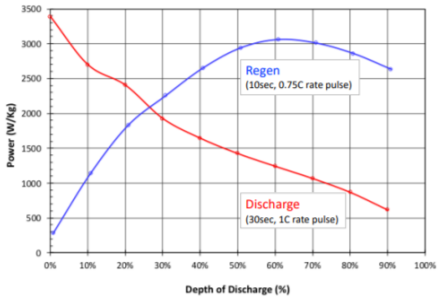
## *Applications:*

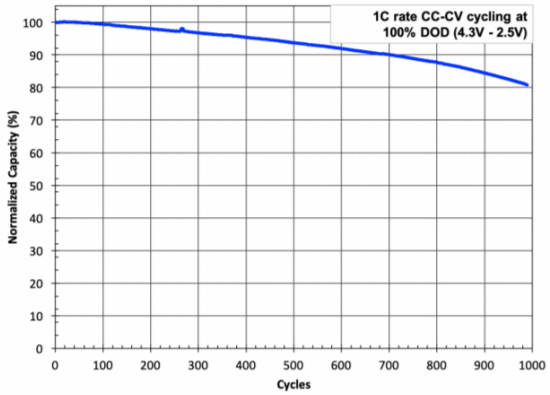
✓ Electric vehicles (EVs and PHEVs)
✓ Unmanned aerial vehicles (UAVs)

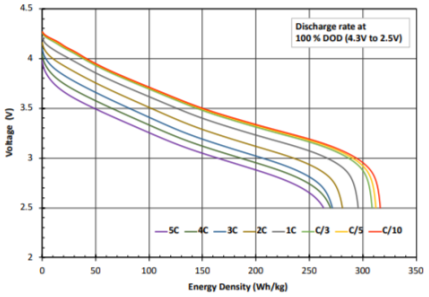


Dimensions in mm (not to scale)

| Cell Characteristics at 30°C | Units | Cell Level (BOL) |
|---|---|---|
| Cell Capacity @ C/3 Rate | Ah | 51 |
| Useable Specific Energy @ C/3 Rate | Wh/kg | 305 |
| Useable Energy Density @ C/3 Rate | Wh/L | 640 |
| Peak Specific Discharge Power, 30 s Pulse | W/kg | 850 |
| Peak Specific Regen Power, 10 s Pulse | W/kg | 300 |
| Peak Discharge Power Density, 30 s Pulse | W/L | 2000 |
| Cycle Life (100% DOD at 1C-1C rate ) | Cycles | >1000 |
| Fast High Rate Charge | Minutes | >80% ΔSOC in 15 min |
| Maximum Self-discharge | %/month | < 1 |
| Operating Temperature | °C | -30 to +52 |
| Average Voltage | V | 3.46 |
| Cell Weight | g | 592 |
| Cell Dimensions | mm | 320 x 102 x 10 |
| Voltage Range | V | 4.3 to 2.5 |



| Companies | Technology | Weight Energy Density [Wh/kg] | Volume Energy Density [Wh/l] | Cycle life | Nominal Voltage [V] | Charging Voltage [V] | Discharge Temp. Range [°C] | Charge Temp. Range [°C] | Peoduction Scale Status |
|---|---|---|---|---|---|---|---|---|---|
| American Lithium Energy - (USA) | Li-Ion with 100% Silicon Nanowire Anode - LCO/NMC Cathode | 300 | 700 | 200 | 3.4 | 4.2 | from -30 to 60 | from 0 to 45 | Prototype |
| Amprius - (USA) | Li-Ion with 100% Silicon Nanowire Anode - LCO/NMC Cathode | 450 | 1200 | 200-700 | 3.6 | 4.35 | from -30 to 55 | from -10 to 55 | Commercial |
| Cuberg - (USA) | Lithium Metal Anode and high voltage cathode | 405 | 800 | 200 | 3.8 | 4.35 | from -20 to 60 | from -10 to 50 | Prototype |
| Eagle Picher - (USA) | Li-Ion with Silicon Grphite Anode | 300 | 567 | 200 | 3.55 | 4.2 | from -20 to 55 | Not Mention | Prototype |
| Endlis Energy - (USA) | Lithium Metal Anode and Sulfur cathode | 400 | | | | | | | Prototype |
| Enevate - (USA) | Li-Ion with High Silicon Grphite Anode (70% silicon) | 350 | 1000 | 1000 | 3.7 | 4.3 | from -20 to 60 | from 0 to 45 | Prototype |
| Enovix - (USA) | Li-Ion with 100% Silicon Nanowire Anode - LCO/NMC Cathode | 300 | 1000 | 500 | 3.8 | 4.35 | from -20 to 60 | from 0 to 45 | Prototype |
| Eocell - (USA) | Li-Ion with Silicon Grphite Anode and solid state electrolyte | 300 | 693 | 1000 | 3.6 | 4.2 | | | Prototype |
| Factorial - (USA) | Lithium metal anode with solid electrolite and NMC cathode | 350-400 | 750-1000 | 1000 | | 4.2 | | | Prototype |
| High Power - (China) | Li-Ion with Silicon Grphite Anode and LCO high Voltage Cathode | 300 | 750 | 500 | 3.85 | 4.5 | from -20 to 60 | from 0 to 45 | Commercial |
| Leydenjar | Li-Ion with 100% Silicon Anode -NMC Cathode | 450 | 1350 | 200 | | 4.3 | | | Prototype |
| Navitas Systems - (USA) | Lithium Metal Anode and Sulfur cathode | 300 | | 250 | 2.2 | 2.3 | | | Prototype |
| Nextech Batteries - (USA) | Lithium Metal Anode and Sulfur cathode | 410 | | | | 2.41 | | | Prototype |

| Companies | Technology | Weight Energy Density [Wh/kg] | Volume Energy Density [Wh/l] | Cycle life | Nominal Voltage [V] | Charging Voltage [V] | Discharge Temp. Range [°C] | Charge Temp. Range [°C] | Peoduction Scale Status |
|---|---|---|---|---|---|---|---|---|---|
| Quantum Scape - (USA) | Lithium Metal Anode, Solid Electrolyte and NMC cathode | 400 | 1050 | 1100 | 3.7 | 4.2 | from -30 to 60 | from 0 to 45 | Prototype |
| Siilion (Aquired by Tesla) - (USA) | Li-Ion with high portion Silicon Anode -NMC Cathode | 300 | | 450 | 3.8 | 4.35 | | | Prototype |
| Sion Power - (USA) | Lithium metal anode with NMC cathode | 500 | 1000 | 350 | 3.8 | 4.4 | from -20 to 45 | from 0 to 45 | Prototype |
| Solid Energy - (USA) | Lithium metal anode with semi solid electrolite and LCO/NMC cathode | 400 | 1000 | 600 | 3.83 | 4.3 | from -20 to 60 | from 0 to 45 | Prototype |
| Solid Power - (USA) | Lithium metal anode with solid electrolite and NMC cathode | 320 | 660 | 250 | 3.8 | 4.3 | | | Prototype |
| Terawatt - (USA) | Lithium metal anode withsolid electrolite and NMC cathode | 432 | 1122 | | | | | | Prototype |
| Zenlabs Technologies - (USA) | Li-Ion with 100% Silicon Anode -NMC Cathode | 305 | 640 | 1000 | 3.46 | 4.3 | from -30 to 52 | | Prototype |
| Leydenjar | Li-Ion with 100% Silicon Anode -NMC Cathode | 450 | 1350 | 200 | | 4.3 | | | Prototype |
| RGS Development | | | | | | | | | |
| Bodi Energy | | | | | | | | | |



# Shmuel De-Leon
# Shmuel De-Leon Energy Ltd
# www.sdle.co.il
# shmuel@sdle.co.il


**Information for presentation obtained by:**

1. **Public web sources.**
2. **Shmuel De-Leon Battery/Energy Sources DataBase ® (Includes 29000 cell PDF data sheets ) http://www.sdle.co.il/Default.asp?sType=0&PageId=45580**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