# Battery Needs and Challenges in the Automotive Space

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<th><strong>Battery Need:</strong></th>
<th><strong>Battery Challenge:</strong></th>
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<td>Higher Energy Density</td>
<td>Lower Power, Cycle Life</td>
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<td>Fast Charge</td>
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<td>Longer Automotive Life</td>
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<td>Cycle Life</td>
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<td>Lower Costs</td>
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<td>Processing, Materials</td>
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TECHNOLOGY OVERVIEW

Fast Charging due to Metal Foam Architecture:
1. Li⁺ moves fast through in liquid through pores to Silicon surface
2. Silicon is thin, so Li⁺ moves more quickly to reaction site in middle of silicon
3. Electron moves fast through metal scaffold to silicon surface
4. Electron moves quickly through thin silicon to reaction site
Electrode fabrication process

- **Electroplating**
  - Mass Production
  - Materials Refinement

- **>99.4% Pure Materials**
  - Starting Raw Materials: 80% ~ 95% pure

- **Simplified Manufacturing Process**
  - Combines material synthesis and fabrication

- **Variety of Substrates**
  - Metal Foils
  - Metal Foams
  - Carbon Foams and Fibers
  - Opportunities for New Applications

Electroplating bath:
made of lower purity raw materials

Electroplating process:
Minutes, not hours

Electrode rinsing (in water) & drying
**DirectPlate™**

Enables High Packing Density

LCO electroplated on Al foil

- Direct deposition of active battery materials on foil
- Up to 250 micron thick
- No binders
- No conductive additives
- Up to ~ 90% volume fraction of active materials
- Strong adhesion between active materials and current collectors
DirectPlate™
- Lithium Cobalt Oxide
High Power LCO Cathode
- Realized via DirectPlate™

Coin cell-half cell (vs. Li/Li⁺)
10C charge current

State of Charge (%)
Charge Time (min)

- LCO, 2.2 mAh/cm² (Xerion)
- LCO, 3.0 mAh/cm² (Xerion)
- LCO, 3.5 mAh/cm² (Xerion)
DirectPlate™: Robust Battery Structures
- LCO cathode Scotch Tape Adhesion Test
DirectPlate™ Enables High Flexibility

Electrodes rolled at ~ 2.5 mm radius

After rolling 1000 times

Conventional LCO    DirectPlate™ LCO

Discharge profile after rolling

**Conventional LCO electrode**

- 0 rolls
- 100 rolls
- 500 rolls

**DirectPlate™ LCO electrode**

- 0 rolls
- 1000 rolls
**DirectPlate™**
- A new method to make cathode for cable batteries

LG Chem’s Cable Batteries

LCO coated wire

1ST cycle of LCO coated wire

1.2 1.0 0.8 0.6 0.4 0.2 0 4.3 4.2 4.1 4.0 3.9 3.8 3.7 3.6 3.5 3.4 3.3 3.2 3.1 3 0.8 0.6 0.4 0.2 0 1.2

Capacity/mA.h

Packaging Insulator  Al wire  Separator

Cathode Composite (LiCoO₂)  Ni-Sn Anode (Hollow-Spiral)
StructurePore™
- Enhance battery performance

DirectPlate™

StructurePore™:
- High power cathode
- High energy anode
  - silicon
  - tin
  - lithium
- Scale-up
XABC SILICON STRUCTURE PORE CONCEPT

Structure pore Ni foam

Fast silicon electrodeposition

Discharge cycle and associated contraction

Charge cycle and associated expansion

Pore space accommodates silicon expansion

Returns nearly to original state
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XERION TECHNOLOGY PRODUCES HIGH ENERGY BATTERIES USING POROUS SILICON

- Fast charging
- Fast, Direct plating
- Conformal deposition of silicon on 3D scaffold
- No need for copper foil
- No slurry processing needed
- Silicon much cheaper than graphite
- Good cycle life

Metallic 3D scaffold

Si coating

~100 – 500 nm coating
XABC FAST CHARGE SILICON HALF CELL
SIGNIFICANTLY OUTPERFORMS ‘HIGH-POWER’ COMMERCIAL GRAPHITE ELECTRODE

**Diagram:**
- **XABC Si**: 2.6 mAh/cm², 43 μm, 600 mAh/cm³
- **Commercial Graphite**: 2.0 mAh/cm², 51 μm, 400 mAh/cm³

**Graph:**
- SOC (%) vs. Time (min) for XABC Si and Commercial Graphite
GOOD HALF CELL CYCLE LIFE IS ENABLED BY INTERNAL POROSITY, NANOSTRUCTURED MORPHOLOGY AND OPTIMIZED SURFACE AREA

- High silicon loading
- Minimal capacity degradation

0.05 - 1V vs. Li/Li$^+$ 23°C, Coin
Anode: Si010218-3_1 (~3.695 mAh/cm²/side, 144 µm thick)
Cathode: NMC622, 96%, BIC (~3.45 mAh/cm²)
Area: 5.75 x 5.6 cm²
Packaging: 71 µm laminate
Separator: 12 µm
Capacity: 173.3 mAh
Average Voltage at 1C charge: 3.334 V
CHARGE RATE ANALYSIS SHOWS THAT SI BASED FULL CELLS CAN BE CHARGED AT FAST RATE WITHOUT VISIBLE SIGNS OF LI PLATING

Considerable Li plating on commercial graphite anode with fast charging

4.2 – 2.5 V 23°C, Coin
## FULL CELL PROTOTYPES
### EXPECTED ENERGY / POWER DENSITY

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<tr>
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<th>Present</th>
<th>Optimized</th>
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<tr>
<td>Energy (Wh/l) @ 1C</td>
<td>700</td>
<td>800</td>
</tr>
<tr>
<td>Energy (Wh/kg) @ 1C</td>
<td>300</td>
<td>350</td>
</tr>
<tr>
<td>Power (Wh/l), RT, 50% SOC, 5C, 10S</td>
<td>3700</td>
<td>4000</td>
</tr>
<tr>
<td>Power (Wh/kg), RT, 50% SOC, 5C, 10S</td>
<td>1600</td>
<td>1775</td>
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**NOVEL MANUFACTURING PROCESS**

Can be quickly customized with minimal change in tooling.

### High Power
- Highly structured, fast charge
- Markets:
  - Hybrid Vehicles
  - Drones
  - Power Tools
  - National Defense

### Flexible
- 3000 flex cycles, no degradation
- Markets:
  - Wearables
  - Internet of Things
  - Medical

### Very High Energy
- Thick electrodes, no binder
- Markets:
  - All-Electric Vehicles
  - Grid-Scale Storage
  - Cell Phones

### Micro-battery
- Fab-compatible, high energy
- Markets:
  - Embedded Electronics
  - Bluetooth/RFID devices

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*Because Electrodeposition (Electroplating) is also a refinement technique, it offers high potential to reduce costs and open new sources for less pure lithium materials.*