FMC’s Revolutionary Stabilized Lithium Metal Powder (SLMP®)

FMC Lithium Technology Seminar - Battery Japan

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#2 Lithium producer in world (revenue basis)

- **Integrated operational footprint:**
  - 5 production sites worldwide
  - R&D presence in U.S., India, China
  - One of world’s top lithium resources

- **Industry Innovator:**
  - Unique brine process technology
  - Proprietary cathode development

- **Market leader:**
  - #1 supplier: LiOH, LiCl, specialty salts
  - Leader in downstream metals, organics

- **Commitment to the industry:**
  - First carbonate supply to Li Ion batteries
  - Argentine expansion(s) underway

### Our Global Locations: Argentina, China, India, Japan, United Kingdom, United States, and Taiwan.
Brine Expansion

- Salar del Hombre Muerto, Argentina
- Located in the high Andes at about 4000 m or 14,000 feet above sea level
- 30% expansion over current capacity

Creating new ponds

Existing Salar ponds
Addressing New Product Requirements

Grades of:
- Li Carbonate
  - Industrial Grade
  - Technical Grade
  - Micronized Technical Grade
  - Battery Grade
  - Micronized Battery Grade

- Li Hydroxide
  - Technical Grade
  - Purified
  - Battery Quality Grade

Li metal

Stabilized Lithium Metal Powder (SLMP®)
FMC’s Commitment to the Industry

- **2011: Expansion of Li salt production**
  - 30% increase over current levels
  - Actively working on second phase capacity addition

- **2008: Opened Center of Lithium Energy Advanced Research (CLEAR) Lab**
  - Constructed laminated Li-ion cells; trained industry and academia in Li safe handling
  - Developing customized solutions for major energy storage device manufacturers

- **2004: Developed revolutionary Anode lithiation technology (SLMP)**
  - Stabilized Lithium Metal Powder (SLMP)
  - Improves energy density of Li-ion cells, increases calendar life, and reduces cost

- **1995: Entered Cathode market as advanced materials supplier**
  - Developed significant intellectual property for LiCoO$_2$ and LiNiO$_2$ families
  - Developed unique composition enabling high rate capability and low impedance build

- **1991-1992: Entered market as Li salts supplier**
  - First to supply carbonate to SONY for their lithium cobaltate production
  - Became a leading supplier of hydroxide to battery market
Li-ion battery will not work without Li, but Li is not the cost driver. Li is only a small part of the battery cost.

Source: Deutsche Bank

Large format battery (i.e. automotive):
- Cells (150 Cells) $7,395
- Mechanical parts, packaging, labor $4,005
- Margin $3,600
- Total Packed Cost (25 kWh) $15,000

*Assuming NCM cathode

- Lithium is ~1.5% of cell cost
- Less than 1% of final battery cost

Li-ion battery will not work without Li, but Li is not the cost driver. Li is only a small part of the battery cost.
Industry needs “Out of Box Thinking” for Lower Cost, Higher Energy, and Better Safety

• New electrode materials are necessary to increase energy density of Li-ion batteries

• Li-ion technology has been expanding into large format batteries

• Automotive use demands lower cost and improved safety
  – Need more choices for active and inactive materials!
  – Need to break the current limitation that all lithium has to come from the cathode of the Li-ion cell.
Lectro® Max 100 Series, Stabilized Lithium Metal Powder

Normal lithium powder
- Can only be handled in an argon filled glove box
- Not commercially available as powder

Stabilized Lithium Metal Powder (SLMP®)
- Safe to handle in a dry room
- Can be transported by air or sea
- Metallic Li content is at least 98%

FMC has been producing lithium powder for its own use at the level of hundreds of tons/year for over 30 years
Dry Room Stability

**SLMP-derived thin foil**
- SLMP coated onto Cu foil and pressed at 12,000 lbs per 1.2 cm² resulting in thin “lithium foils”
- Electrodes exposed to a Dry Room environment with Dew Point of ~ -50°C for predetermined time period
- Active Li was measured by the specific capacity from those electrodes using half cells. The cells were charged at 0.1mA to 3.0 V. The average loading per cell was about 1mg.

**SLMP Powder**
- Dew Point -30°C or better
- Material spread in thin layer in Petri dishes
- Material is not disturbed during exposure
- Material is thoroughly mixed prior to analytical analyses

Ultra thin Li foils generated with SLMP – stability same as foils, and electrochemical activity same as foils
Benefits of SLMP®

Opening up choices for active materials

• Anode choice no longer limited to graphite.
  – Allows the use of new materials with both large reversible and irreversible capacities, such as Si composites and Sn intermetallics.

• Cathode choice no longer limited to lithium providing materials.
  – Much wider selections of non lithium providing materials offering more possibilities: more overcharge tolerant, lower cost, and larger capacities.

• Use of SLMP in battery material synthesis
  – Si and Sn Composite anode materials

Bottom line: increase in energy density, improvements in safety and calendar life, cost reductions

Using Lithium from SLMP will cost less than using Lithium from LiCoO₂ cathode and you can pocket other advantages too
A non-lithium providing cathode is now possible – lower cost and safer

(Graphite+SLMP)/MnO₂  (Graphite+SLMP)/ BiF₃ Nanocomposite

![Graph showing specific capacity over cycle number](image1)

![Graph showing cell voltage over discharge time](image2)
High capacity anode is now possible

* Data courtesy of Shin Etsu
First Cycle Efficiency Improvement in LiCoO$_2$/Graphite System Using SLMP
(Data courtesy of MaxPower Corporation)
Cell examples

A Li-ion cell: (Graphite+SLMP)/ LiMn$_2$O$_4$

First Cycle Efficiency Improvement in LiMn$_2$O$_4$/Graphite System Using SLMP, and it cycles better too!
First Cycle Efficiency Improvement in LiMn$_2$O$_4$/Hard Carbon System Using SLMP, more benefits for automotive systems!
SLMP® Introduction into the Cell

Two general methods to apply SLMP

**Slurry application**
- Include SLMP in the slurry mix when the anode sheet is being cast – no additional step but the slurry solvent needs to be compatible with lithium.

**Surface application**
- Coat SLMP suspension on the surface of a pre-fabricated anode sheet – no need to change the existing anode fabrication process.
Industrially Scalable Processes

- Set-up designed for D-cell production with SLMP™ Technology incorporated

Video clip
- Slurry based
- Micro Gravure coating method
Lithium Metal Carrier Film Technology (LMCF)

SLMP can be transferred to electrode surface through a carrier film

Solvent Free!
Advantages

- No solvent involved at cell assembly place
- Just attach, press and peel
First Cycle Efficiency Improvement Using LMCF Technology

LMCF Applied to MCMB prefabricated anode sheet

LMCF Applied to Hard Carbon prefabricated anode sheet

Anode formulation: 90% MCMB 25-28, 5% PVdF, 5% Conductive Carbon (Super P)

Anode formulation: 90% Carbotron PS(F), 7% PVdF, 3% Conductive Carbon (Super P)

Cathode composition: \( \text{LiMn}_2\text{O}_4 \) (90%), Super P carbon black (5%), Kynar 761 PVdF (5%). We used Novolyte 1M LiPF_6 /EC+DEC (1:1) electrolyte.

The cell test protocol: constant current charge at 0.5 mA/cm² to 4.3 V followed by 4 hours constant voltage charge at 4.3 V and constant current discharge at 0.5 mA/cm² to 3.0 V.
SLMP Lithiation vs. Electrochemical Lithiation

**Figure.** The capacity-voltage profiles of the 1st cycle for the baseline, SLMP lithiated, and electrochemically lithiated cells.

**Figure.** The capacity-voltage profiles of the 2nd cycle for the baseline, SLMP lithiated, and electrochemically lithiated cells.

**Procedure to construct an electrochemically lithiated cell:**

1. Assemble baseline hard carbon / LiMn$_2$O$_4$ pouch cells with no SLMP added
2. Charge cells to 30 mAh and disassemble to recover the partially charged hard carbon anode (assumption: 3000 mAh/g capacity for SLMP)
3. Assemble new pouch cell using partially lithiated anode and spinel cathode

Cycle cells using the following protocol: constant current charge at 0.25 mA/cm$^2$ to 4.3 V, and then constant voltage charge at 4.3 V; the whole charge process proceeded for about 10 hours followed by a constant current discharge at 0.25 mA/cm$^2$ to 3.0 V.
Lithiation with thin Li foils – a very slow process

Rolled Li thin foil (<30 micron): macro view

Thin Li foil as applied onto the surface of pre-fabricated anode

After 7 days of storage at 25°C

After 9 days of storage at 25°C

Graphite anode
Lithiation with thin Li foils – a very slow process

Rolled Li thin foil (<30 micron): macro view

Prior to electrolyte addition

after electrolyte addition, time=1hr

time=1 day

time=7 days
The Li concentration inside of the graphite electrode near the foil remains high due to slow Li diffusion in graphite → it takes a long time for Li concentration to equalize due to the distance Li has to travel.

SLMP provides a localized Li distribution → much faster to reach equilibrium with SLMP treated electrode compared to foil treated one.

Unless you want to wait for days, use SLMP to lithiate your electrode – much faster diffusion
Summary

• FMC Lithium has an extensive play in the lithium-ion battery market, from providing basic lithium raw materials to developing new materials and technologies.

• Out of box thinking is needed to meet the more challenging requirements of large format batteries.

• SLMP® enables more material choices to meet the increasing demands for more energy, lower cost and better safety for Li-ion batteries by providing an independent source of lithium for Li-ion batteries.

• SLMP® can be introduced into the cell through industrially scalable methods.

We welcome the Battery Community to visit CLEAR and apply SLMP onto your current and advanced electrode materials and get trained in safe Lithium handling.
CLEAR Lab Capabilities

• Center for Lithium Energy Advanced Research

• Located at our Bessemer City, North Carolina plant

• Equipped with a state-of-the-art R&D Dry Room for testing rechargeable lithium-ion battery components

• Used for development and demonstration of SLMP®—stabilized lithium metal powder

• Used by customers for evaluation of their proprietary material with SLMP
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