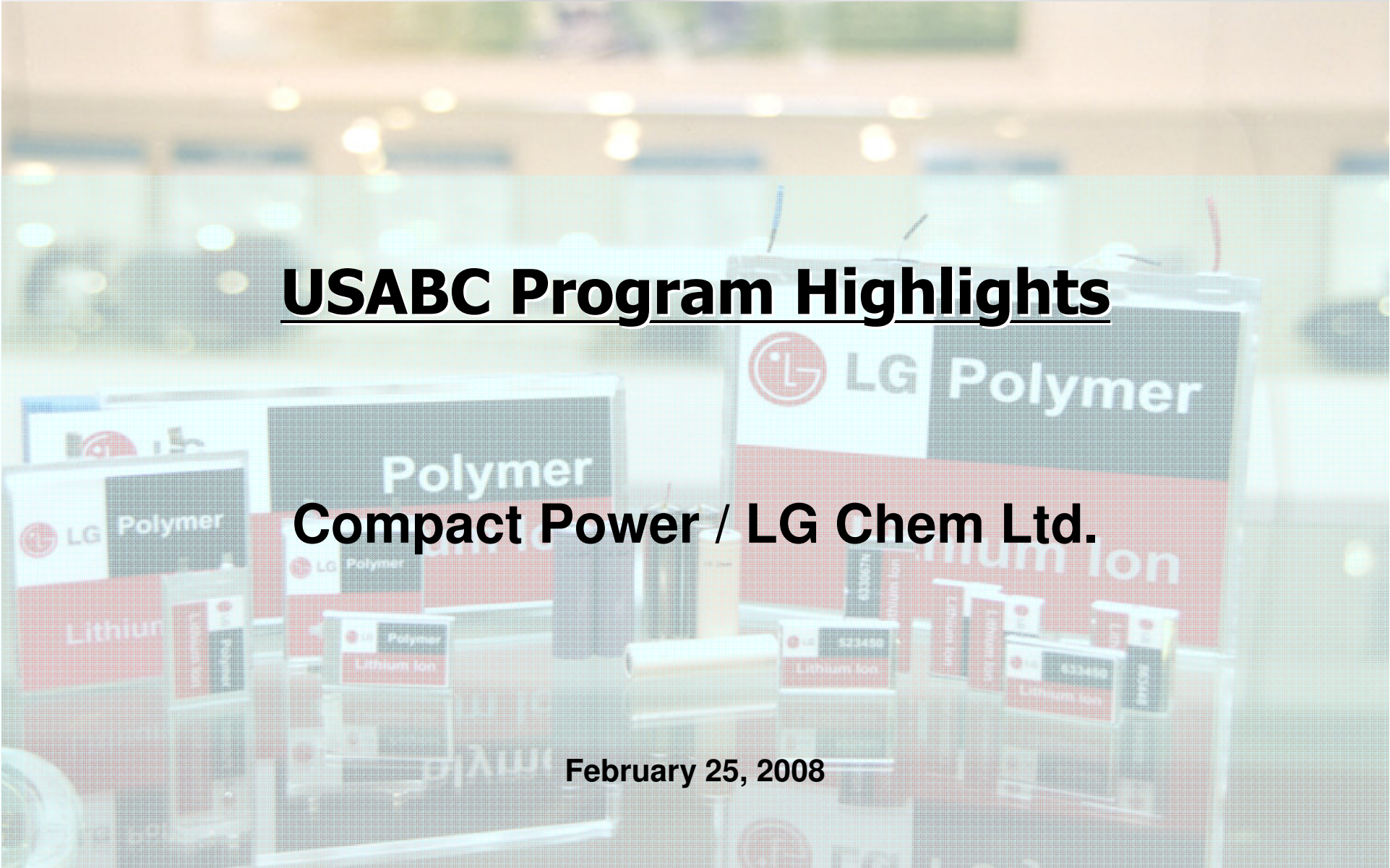




USABC Program Highlights

Compact Power / LG Chem Ltd.

February 25, 2008

Outline

- **CPI/LG Chem Overview**
- **HEV/PHEV Cell Technology**
- **Module/Pack Development Studies**

CPI Mission

- **CPI was established in Colorado in 2000 to focus on vehicular batteries. Moved to Troy, Michigan, in 2005.**
- **Partner-of-Choice for Turn-key solutions for HEV/PHEV applications.**
- **Accumulated know-how in automotive and battery business**
- **CEO: Dr. Prabhakar Patil, 27 yrs with Ford (Chief Engineer of Escape Hybrid)**
- **Current Employees: 40**
- **Agility of a start-up backed by the resources of LG Group**

The LG Group

Global presence in over 120 countries with **US\$89 Billion** in revenue and **160,000 employees**.

*“Creating a Solid, Competitive,
Strong and Dynamic LG”*



- ✓ **Holding Company**
- ✓ **Chemicals**
- ✓ **Electronics / Display**
- ✓ **Telecommunications**



LG Group: Business Segments

LG Group focuses on 3 business areas and has 29 subsidiaries.



Chemicals(7)

LG Chem

- LG Petrochemicals
- LG Dow PC

LG Household & Healthcare

LG Life Science

LG MMA

...

Electronics(8)

LG Electronics

- LG Phillips LCD
- LG Innotek
- LG Micron

Siltron

...

Telecommunications & Services(14)

LG Telecom

LG Dacom

LG Powercom

LG CNS

LG Sports

SERVEONE

...

CPI Focus: Pack Design/Production

- **Battery Pack Concepts and Designs**
 - Power & Signal Architectures
 - Packaging
 - Thermal Management
- **Battery Management Systems**
 - Charge control algorithms (State-of-Charge estimation)
 - Vehicle interface
 - Diagnostics (State-of-Health estimation)
- **Battery Pack Production and Support**
 - Battery Program Management for US Customers
 - Pack-level Analysis, Validation, and Verification
 - System Integration & Test Support
 - Prototypes

Program Descriptions

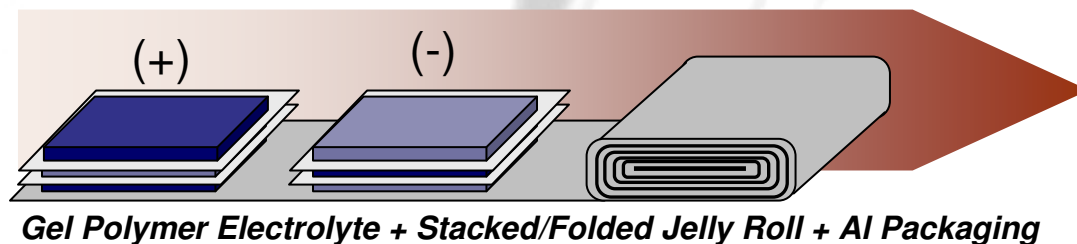
- HEV Program \$6.3M _(65/35) 18 Months
- PHEV Program \$12.9M _(65/35) 27 Months

HEV Program Objectives

- **Demonstrate Calendar-life**
- **Demonstrate cycle-life**
- **Demonstrate cold-cranking capability**
- **Studies on abuse-tolerance, laminated packaging and cost**

Cell Construction Features

- Unique Design (Stacking of Plates & Folding)
 - High rate capability (*easy current collection*)
 - More suitable for scaling-up (*handling of long electrodes not required*)
 - Maintains dimensional stability during cycling
 - Proven technology in mass production of small cells
- Robust laminated packaging design
 - Much simpler, more reliable and less expensive manufacturing
 - Easy to change cell footprint



Demonstrate Calendar-Life

- **Base spinel**
 - Abundant, easy synthesis, low and stable cost, high power
 - But poor calendar-life due to Mn^{2+} dissolution, Mn plating on carbon anode.
- **Approaches to improve calendar life while maintaining spinel advantages**
 - Different dopants, morphologies, coatings, additives
- **Protect the anode**
 - Coatings, additives

Demonstrate Calendar-Life

➤ Results

- 2- 3 yrs life in 2004
- > 10 yrs in 2006
- > 15 yrs now

➤ We acknowledge here with deep gratitude the technical help we received from the USABC Team Members in aligning our testing methodologies and evaluation criteria with those of the USABC!

Demonstrate Cycle-life

- **Key change**

- **Anode modification**

- **Results**

- **< 160k cycles in 2004**

- **> 550k cycles in 2007**

- **Next version has even better life!**

Other Attributes:

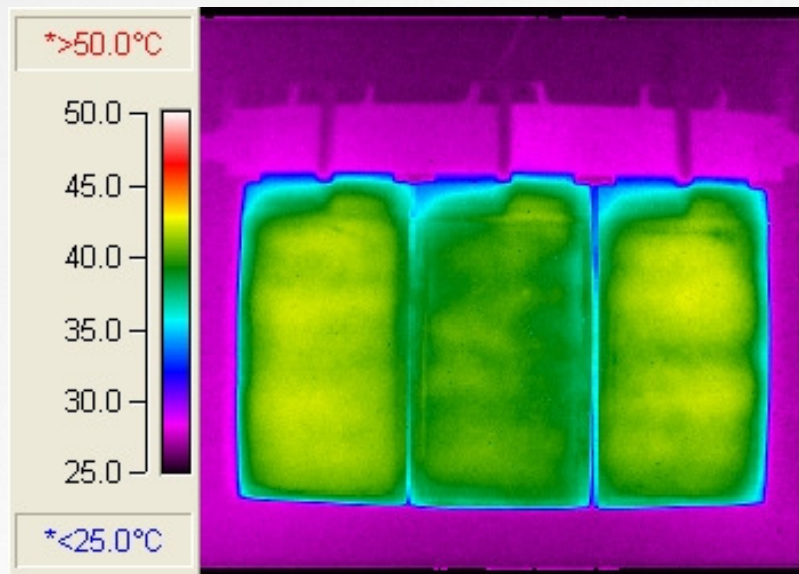
- Cold-Cranking Capability (5kW at -30°C)
 - G4.3 cells are capable of meeting the target
- Cost (\$500/pack)
 - Have we reached the target as yet?
 - No, but we are working on it and have made significant strides toward that goal.

air

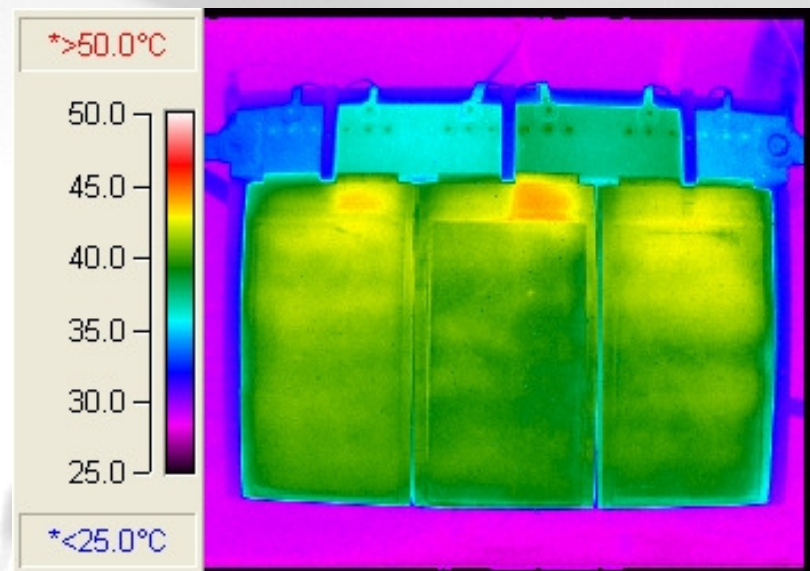
Efficient Heat-Transfer

Temperature distributions at end of test

30C discharge, 145 seconds



Geometric cycle, 17 minutes



- Electrochemically active area uniform, within 2-3 °C
- Courtesy of NREL: Dr. Pesaran's Team

Improved Abuse-Tolerance

- **Key Cell features enhance abuse-tolerance**
 - **Spinel-based chemistry**
 - **Proprietary separator-** higher puncture strength, lower shrinkage
 - **Laminated Packaging**
- **Results: Outstanding safety**
 - **Short-circuit**
 - Cell bulging only, Temp <90°C
 - **Nail-penetration**
 - No smoke, no fire. Temp <100°C
 - **Overcharge**
 - No explosion, no fire.
 - **Thermal stability**
 - No explosion, no fire

PHEV Program

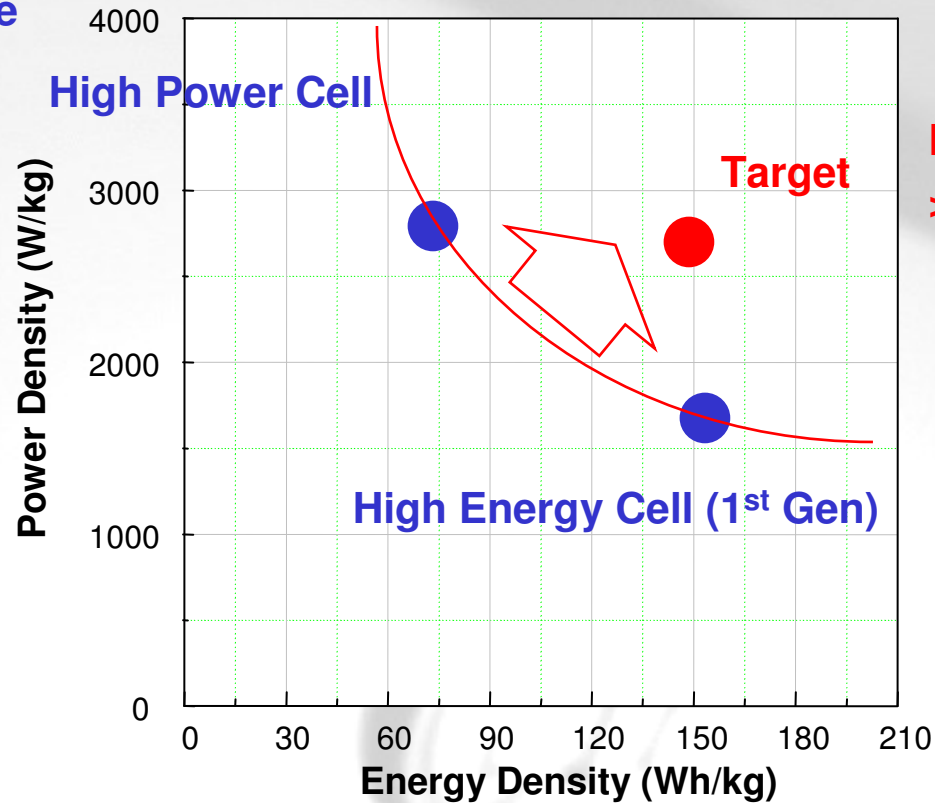
- PHEV cell combines both high power and high energy

Focus of Work

- Thermal issues
- Cycle-life
- Abuse-tolerance

PHEV cell design characteristics:

300,000 cycles
>15 years of life



Meet Cycle-life with
>15 years of life

Cycle life at 100% DOD
<5 years of life

Module and Pack Technologies



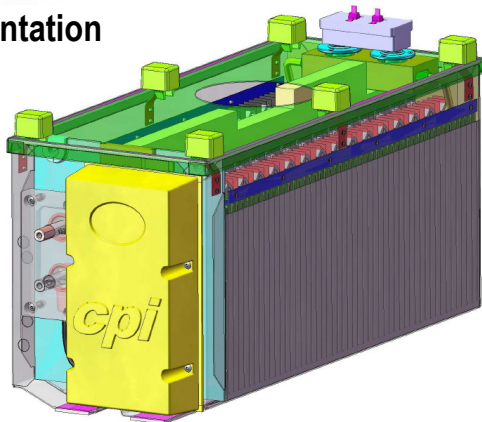
Scope of Module/Pack Work

- Engineered for
 - High energy/Power density
 - Minimum overheads- mass, volume, cost
 - Thermal management
 - Long life (Robustness, Cell Protection)
 - Superior Abuse-Tolerance

Laminated Packaging: Opportunities and Challenges in Module and Pack Designs

- Laminated packaging, prismatic cell design allows for a variety of layouts to “fit” in small or odd-shaped areas
- Challenges include
 - How to hold the cells in place?
 - How do you connect the cell tabs (flat) either in series or in parallel?

Vertical cell orientation



Horizontal cell orientation

Developed State of Charge (SOC) Estimation

- **Studies a variety of methods**
 - OCV, “Tino”, Coulom counting etc.
- **Sigma-Point Kalman Filter (SPKF) found to be superior**
 - Model-based “state-space” estimator
 - Self-correcting; accounts for:
 - Rapidly-changing parameters (hysteresis & polarization time constants, etc.)
 - Slowly changing parameters (e.g., due to cell aging)
 - Uses current measurements for short term SOC dynamics; voltage for longer term dynamics
 - * Uses coulomb counting in closed-loop environment to improve accuracy
 - Simulation Results: +/- 3% within 100sec at > -20 °C; +/- 5% @ -20 °C

GM Volt Pack



gm-volt.com

- **Delivered 4 packs so far.**
- **The design and development of the Volt pack benefited significantly from the work we carried out under the USABC program.**

Conclusions

- Significant progress within the past few years have been made by LGC/CPI in spinel-based chemistry to satisfy automotive battery performance, life, abuse-tolerance and cost requirements.

Acknowledgements

- **LG Chem team (Seungdon Choi and his team-members)**
- **USABC for their financial and technical support in course of these programs (DoE: Tien Duong, Dave Howell, Jim Barnes, Jack Deppe), Big 3: Ahsan Habib, Harshad Tataria, Cyrus Ashtiani, Rick Lagerstrom, Kent Snyder, Ron Elder and Josephine Lee)**
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